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THE UNIVERSITY OF ALBERTA

POTASSIUM STATUS OF SOME ALBERTA SOILS HAVING

LOW POTASSIUM SOIL TEST VALUES

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA

SEPTEMBER, 1964

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and
recommend to the Faculty of Graduate Studies for acceptance, a
thesis entitled "Potassium Status of Some Alberta Soils Having
Low Potassium Soil Test Values" submitted by Robert William
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degree of Master of Science.

ABSTRACT

The potassium values of an appreciable number of soil samples received by the Agricultural Soil and Feed Testing Laboratory in recent years have been less than 50 lb./ac. (HAc extraction method). In order to determine whether these soils should be rated as low in potassium, greenhouse, field and laboratory studies were carried out on selected soils.

Increased yields of barley occurred in the greenhouse from potassium fertilized Aa horizons of the Thin Black Solod, Wetaskiwin and Camrose soils and of alfalfa for the Wetaskiwin and Camrose soils. However, the increases of barley and alfalfa yields were small on the Winterburn soil, which tested over 50 lb./ac. of K.

The Aa horizon of the Winterburn soil had the highest potassium content of all the soils by the four methods used, which **had** as extractants 0.024N HAc, 1N NH$_4$Ac, 0.1N HNO$_3$ and boiling 1N HNO$_3$. The British Columbia and Ontario soils used (which responded to potassium) had the lowest potassium content. The potassium levels in most of the soils with values less than 50 lb./ac. in the Aa horizon increased with increase in depth of profile. No correlation occurred between the 10-11 $\overset{o}{A}$ peaks of the clay fraction and exchangeable or hydrolyzable potassium content of the soils.

Analyses of alfalfa grown in the greenhouse on the Thin Black Solod, Camrose and Wetaskiwin revealed that the plants had below the critical 1 per cent potassium content on the check plots while the Winterburn soil had 1.72 per cent. Plants from the check plots of field experiments on soils testing less than 50 lb./ac. of K (HAc method) had greater than 1 per cent but below 1.5 per cent. However, responses were not obtained from potassium application on grass-legume stands on these soils during the summers of 1963 and 1964. Moisture conditions were adverse and yields were low in all plots,

consequently more testing is required.

It would appear that the Alberta soils with soil test values less than 50 lb./ac. of K (HAc) should be rated low in potassium content. This suggests the probability of an inadequate potassium supply especially for crops with high potassium requirements.

ACKNOWLEDGEMENTS

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INTRODUCTION

Potassium is needed in large amounts by most plants. The quantity removed from the soil depends on such factors as species of plant, level of available potassium, rate of potassium release, amounts of other elements available, soil moisture, soil aeration and temperature. Potassium is essential for physiological functions such as formation of sugars and starch, synthesis of protein, cell division and growth. It increases resistance to adverse weather conditions such as low soil moisture and low temperature. Potassium improved the rigidity of straw and stalks.

The amount of potassium present in the soils of Alberta has been considered until recently to be more than sufficient for plant needs. Therefore, use of potassium fertilizer has not been recommended to farmers (Alberta Department of Agriculture, 1959; Alberta Advisory Fertilizer Committee, 1963) nor have extensive studies been carried out using this nutrient. In recent years, the Alberta Soil and Feed Testing Laboratory has received thousands of soil samples from farmers and soil tests have ranged from less than 50 lb./ac. (0.06 me./100 g.) to greater than 400 lb./ac. (0.50 me./100 g.) using 0.024 N HAc as an extractant. Generally, soils from the Brown and Thin Black zones tested in the 200 to 400+ range and those from the Black and Grey Wooded zones tested in the 50 to 200 range. Areas also exist in the latter zones where the soil tested less than 50 lb./ac. and this level has been tentatively designated as the borderline between low and medium levels. The total potassium content varies in the same way, with the soils in southern Alberta generally having the highest total potassium and the soils in central and northern Alberta having the lowest amounts. Amounts of total potassium vary from 1-2 per cent. Total potassium content varies only slightly with increasing depth of profile.

However, great variations occur within the same soil zone and are likely the result of differing parent material. Gravenor and Bayrock (1961) stated tills of Alberta are 80 per cent local bedrock material. Therefore the till deposits are derived from differing geological formations and variations in the tills are to be expected. Little work has been done on the characterization of Alberta tills but Pawluk[1] is carrying out at the present time an extensive study of their chemical characteristics.

Kohnke (1937) found by Neubauer test that some soil samples from the Black and Grey Wooded zones of Alberta were deficient in potassium while none from the Brown soil zone were deficient. In the past, fertilizer experiments have shown no significant yield increases due to potassium fertilization (Alberta Advisory Fertilizer Committee Reports, 1958-1963) except in 1962. Some experiments showed a general trend toward higher yields from added potassium on Black and Grey Wooded soils. Goettel (1962) located 11 sites in 1961 representing a fairly wide range of soil potassium values. The sites were in the Black and Thin Black soil zones with soil potassium values (0.024 N HAc method) ranging from 52 to 224 lb./ac. No significant yield responses occurred in 1961 to the four rates of potassium applied. However, the 1962 results (Fertilizer Tests in Alberta, 1962), although erratic, suggested a trend toward increased yields of forage from potassium applications on soils with potassium test values of 42 and 52 lb./ac. Grain plots in 1962 on soils with values less than 50 lb./ac. showed erratic trends toward increased yields from potassium applied in combination with 40 lb. of nitrogen and 80 lb. of phosphorus.

It is evident from the foregoing that only limited information is available on the potassium status of Alberta soils. The fact that a general, although non-significant trend toward increased yields, resulted from potassium

[1] Personal communication from Dr. S. Pawluk, Univ. of Alberta.

fertilization on certain Black and Grey Wooded soils warrants more study
in order to properly assess the problem.

It is the object of this study to characterize certain Alberta soils
having test values less than 50 lb. per acre of potassium and to attempt
to distinguish whether they are actually deficient in this element. The
work was carried out in three phases: (1) continuous cropping of barley and
alfalfa in the greenhouse on soils that received various rates of potassium,
(2) field fertility trials on selected soils (3) laboratory studies including
routine characterization of the soils, rate of potassium release, relative
quantity of the 10-11 $\overset{\circ}{A}$ clay mineral group present and potassium content of
selected plant samples. Two soil profiles of Tolmie loam from Vancouver
Island, British Columbia and the 0-6 inch depth of Burford loam and Guelph
sandy loam from Ontario were obtained for analysis as crops grown on these
soils are known to have given response to potassium fertilization (Gardner
et al, 1960; Millar[1]).

[1] M. H. Millar, Professor of Soils, Guelph, Ontario; Personal Communication.

REVIEW OF LITERATURE

Potassium is present in relatively large quantities in most soils.
The total potassium content of a soil depends on the mineralogical composi-
tion and type and degree of weathering. It generally ranges from low values
in highly weathered A horizons of podsols to high values in slightly weathered
soils rich in potassium feldspars and micas (Wiklander, 1954). It can vary
from a few hundred pounds per acre furrow slice for soils formed on sand-
stone and quartz to 50,000 lb. or more for soils formed from potassium-
bearing minerals (Tisdale and Nelson, 1956). In mineral soils only about 1
per cent of the total potassium is exchangeable. Most is held as constituents
of the primary and secondary minerals or fixed between lattices of the clay
crystals. These soils with large reserves often do not contain enough
available potassium for adequate plant nutrition. The plant must depend
on potassium that was not initially exchangeable or water-soluble for its
requirements.

Forms of Potassium in the Soil

(a) Soluble and Exchangeable Potassium

Soluble potassium is that present as an ion in the soil solution and
is about 1 per cent of the exchangeable potassium. Exchangeable potassium
is defined as the potassium adsorbed on the soil material and is replace-
able with neutral salts in a relatively short time (Wiklander, 1954). The
content of exchangeable potassium is usually less than 1 per cent of the
total potassium (Wiklander, 1954; Arnold, 1962). Soluble and exchangeable
potassium are difficult to distinguish because they are in dynamic equilib-
rium with each other as indicated by the following equation (Mortland, 1961;
Arnold, 1962):

$$\text{Soluble K} \rightleftharpoons \text{Exchangeable K}$$

They are, therefore, usually determined together and expressed as exchangeable potassium. These forms are readily absorbed by plants and are referred to as readily available potassium (Troug and Jones, 1938). This readily available form is derived partly from the break down of primary minerals due to weathering and partly from the release of fixed potassium. The exchangeable potassium never falls below a minimum level characteristic of that soil due to release of potassium from primary and fixed forms (Wiklander, 1954).

An increase of potassium in the soluble form as would occur from the addition of potash fertilizer would cause the equilibrium reaction to proceed toward the exchangeable form. This equilibrium between the two forms is important since soluble potassium is subject to leaching and the adsorption of potassium ion would reduce this loss from the soil. The equilibrium would be affected in a reverse manner if plant roots removed potassium ions from the soil solution. Under certain conditions and in soils with certain 2:1-type clays, exchangeable potassium in excess of equilibrium level can be fixed (Wiklander, 1954; Tisdale and Nelson, 1956; Garman, 1957; Gardner, 1960; Arnold, 1962).

(b) Fixed Potassium

Fixed potassium is that potassium added to a soil which becomes so tightly bound that it is not immediately replaceable with neutral salts. It has been fixed or trapped between the lattices of the clay crystal (Kardos, 1955) due to contraction of the lattice of expanding 2:1-type clay minerals (DeMumbrum, 1958; Mortland, 1958; Ellis and Mortland, 1959). Fixed potassium is also referred to as slowly available or difficultly exchangeable (Arnold, 1962). In this form it is not possible for plants

to utilize it unless release or defixation occurs. Wiklander (1954) stated that fixed potassium is a transition stage between exchangeable potassium and lattice potassium with no distinct boundaries between the three forms.

It has been reported (Reitemeier, 1951; Wiklander, 1954; Tisdale and Nelson 1956; Buckman and Brady, 1960) that an equilibrium between soluble, exchangeable and fixed potassium exists and may be expressed as follows:

$$\text{Soluble } K \rightleftharpoons \text{Exchangeable } K \rightleftharpoons \text{Fixed } K$$
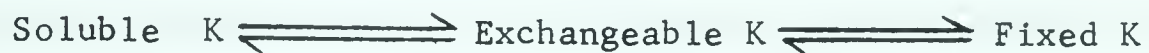
A change in any one of these forms upsets the equilibrium. Addition of potassium fertilizer would cause the level of soluble potassium to increase and the reaction would proceed to the right, with fixation occurring. Plant removal of soluble potassium would produce the opposite reaction with release of fixed potassium taking place.

(c) Lattice Potassium

The potassium bearing primary and clay minerals contain in a non-exchangeable form the greatest portion of the total potassium. This lattice potassium is present in the crystal structure of the mineral and is also referred to as native potassium (Mortland, 1961). Lattice potassium, often referred to as relatively unavailable potassium (Buckman and Brady, 1960), composes 90-98 per cent of all potassium in a mineral soil. These minerals are only very slightly soluble and require weathering to yield their potassium to the available form. Fixed and lattice potassium are often grouped together and called non-exchangeable potassium (Gardner, 1960; Mortland, 1961).

(d) Equilibrium

In general, it is agreed that not only one or two but all forms of potassium are in equilibrium with one another (Bray and Deturk, 1939; Reitemeier, 1951; Pratt and Morse, 1954). However, the exact relationship

of the forms to each other has not been agreed upon. Truog and Jones (1938)

used an equilibrium tank with the compartments representing the forms

of potassium. Their equilibrium state could be represented:

Readily available $\rightleftharpoons$ Slowly available
(soluble and exchangeable) (fixed K)

Relatively unavailable
(lattice K)
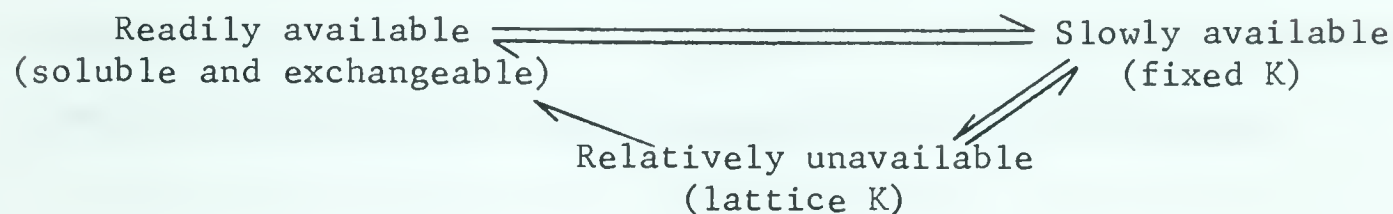
The readily available potassium is in dynamic equilibrium with the slowly

available and is receiving small amounts from the relatively unavailable

form. The slowly available is in equilibrium with the relatively unavailable

but to a much smaller extent than it is with the readily available. Attoe

and Truog (1945) revised the equation by including biotite potassium in

the slowly available form. Biotite is a tri-octahedral micaceous mineral

which is easily weathered (Jackson and Sherman, 1953; Arnold, 1960).

Arnold (1962) further subdivided this equation by separating the readily

available into water soluble and readily exchangeable, showing them in

dynamic equilibrium with one another.

Another form of the equilibrium equation may be expressed (Reitemeier,

1951; Tisdale and Nelson, 1956; Gardner, 1960):

Non-exchangeable K $\rightleftharpoons$ Exchangeable K $\rightleftharpoons$ Soluble K

This equation has fixed and lattice potassium grouped under non-exchangeable.

Reitemeier (1957) stated that the time for equilibrium to be established

between each pair of forms in the foregoing equation increased from right

to left. Wiklander (1954) suggested that the reaction time was rapid in

both directions between soluble and exchangeable potassium. The rate of

reaction, however, from exchangeable to non-exchangeable was fairly rapid

at the beginning and became slower as equilibrium approached. The reverse

or release reaction in contrast was a slow process. The rate at which

fixation or release occurs varies depending upon many factors such as type of minerals present, moisture, and crop being grown.

Garman (1957) disagreed with the widely used schematic equations illustrating equilibrium. He suggested an arrangement of the various forms of soil potassium describing equilibrium conditions as:

$$\text{Exchangeable K}$$
$$\text{Water Soluble K} \rightleftharpoons \text{Adsorbed K} \rightleftharpoons \text{Structural K}$$
$$\text{Non-exchangeable K}$$
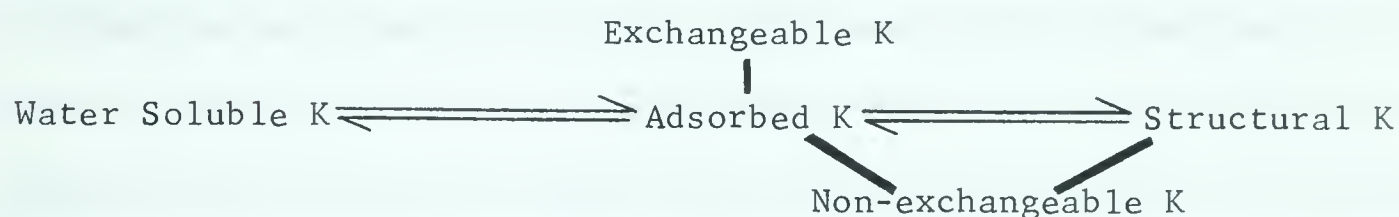
He defined adsorbed potassium as the fraction which is held electrostatically by excess negative charges on the surface of the soil particles and is replaceable by other cations without altering the nature of the exchange material. Structural potassium is the portion of soil potassium present in the crystal structure of both the primary and secondary minerals and includes potassium fixed by the soil. He suggested exchangeable and non-exchangeable potassium are not considered as really constant entities of the soil as they vary with type of extractant and extractant-soil ratio. Therefore exchangeable potassium, which is accepted as being adsorbed on the soil particles, does not necessarily include all the adsorbed potassium as shown by the fact that different amounts are removed by changing the concentration of extractant solution. The amount of adsorbed potassium removed varies with accessibility and bonding energy of the adsorbed potassium. The non-exchangeable potassium may include strongly adsorbed as well as structural potassium. Therefore, if a difference can be detected in the ease of release, they should be considered separately.

Garman (1957) however, failed to consider the difference in ease of release (Ellis and Mortland, 1959) between the fixed potassium and the lattice potassium. Gardner (1960) stated release of fixed potassium to

the readily available form is due to expansion of the lattice of the mineral holding it, while native potassium is released only upon weathering.

Mortland (1961) and Arnold (1962) stated that the categories of soil potassium are arrived at empirically since each is defined by the particular procedure used for its analysis. Various procedures would give a variety of values for any one of the forms. Mortland (1961) stated the mass action type of equation that is sometimes used to represent the equilibrium of the various forms of potassium might be an over simplification of the process. He suggested that release and fixation of potassium in the soil was a diffusion controlled process depending on the concentration of potassium in the solution form and in the "reactive" form. Therefore it would be possible for fixation and release to occur simultaneously in the soil.

Non-exchangeable Potassium

The potassium bearing primary and clay minerals hold the lattice and fixed forms of potassium. This potassium although not immediately available is nevertheless of great importance. Mortland (1961) stated that plants remove much more potassium than the initially exchangeable potassium, thus showing that release of initially non-exchangeable potassium is of importance in the nutrition of plants.

(a) Lattice Potassium

The non-clay minerals generally considered to contain substantial amounts of potassium are the potassium feldspars, microcline and orthoclase (general formula $KALSi_3O_8$), and the micas, biotite and muscovite (general formula $KAL_2(OH)_2ALSi_3O_{10}$). There are other non-clay minerals that contain smaller amounts of potassium. Of the clay minerals, the group of hydrous micas (Grim, 1953) which have a 10-11 $\overset{o}{A}$ spacing, is the only one that contains relatively large amounts of native potassium. The rate at which potassium

is released from the various primary and clay minerals must be considered
in determining their importance in supplying plant requirements.

Reitemeier (1951) reported that orthoclase and microcline contributed
little potassium to oats compared to biotite and muscovite. Jackson and
Sherman (1953) showed the feldspars to be between the two micas in their
weathering sequence with biotite weathering more rapidly and muscovite
more slowly. Leaf (1959) found that microcline has a low level of avail-
able potassium although it contains considerable total potassium. Andreatta
(1955) stated orthoclase releases more potassium than the other minerals
in the soil while biotite and muscovite, although more abundant, are less
significant. Arnold (1962) stated that little is known about the weather-
ing of potassium feldspars although it appears they play only a minor role
in the maintenance of available potassium. Although these feldspars
(Grim, 1953; Mackenzie, 1955) are abundant in many soils they are not
common in the clay size fraction or if present exceed two microns in size;
thus their surface area on which weathering takes place is small. Also,
they are protected by thin coatings of their own insoluble decomposition
products (Arnold, 1962). MacLean and Brydon (1963) found the per cent
of total potassium removed by boiling 1N HNO_3 or H_2resin to be feldspar <
illite < muscovite < biotite. Consequently, it would appear from this review
that the feldspars supply only small amounts of potassium although there
is not complete agreement on this viewpoint.

According to some workers, muscovite releases potassium less readily
than biotite (Mortland et al., 1957; DeMumbrum, 1959). Using growing
plants, ease of potassium release from biotite was much easier than that
from illite and muscovite (Mortland et al., 1957). Mortland et al. (1957)
stated that both biotite and muscovite contained initially easily extract-

able potassium, but once that was removed muscovite released potassium
at a much slower rate than biotite. The di-octahedral muscovites, normally
high in aluminum, are much more stable than the tri-octahedral biotites,
normally high in iron and magnesium (Arnold, 1962; Warshaw and Roy, 1961).
Nevertheless, muscovites are generally of greater importance in the release
of potassium than biotites even though release is slower and more difficult.
This is due to the fact that biotites are seldom found in partially weathered
soils (Mitchell, 1955). The micas, biotite and muscovite, have been found
to release potassium more readily than the potassium feldspars or illites
(Reitemeier, 1951; Jackson and Sherman, 1953; MacLean and Brydon, 1963).
The micas in the soil are present in both the clay and non-clay fractions
and it is difficult to use the separation of soil into these fractions
when discussing potassium in micas.

In the clay fraction the 10-11 $\overset{o}{A}$ group of hydrous micas includes the
illite clay minerals. There is considerable controversy regarding the
meaning of the term illite. Mackenzie (1955) stated it was first used to
describe any clay mica, but now is used only for micas having a K_2O con-
tent of 6 to 8 per cent. Illite is in the weathering sequence between the
micas and the clay mineral vermiculite (Grim, 1953; Jackson and Sherman,
1953; Mackenzie, 1955). The sequence is characterized by a decreasing
potassium content and an increasing H_3O^+ content. Hydrous micas refer to a
broader group which includes hydromuscovite and hydrobiotite, illite,
andreattite and mica-smectite interstratified layers. Hydrobiotite and
hydromuscovite are intermediate between biotite and illite and muscovite and
illite respectively while andreattite is an intermediate between illite
and smectites. However, Arnold (1962) stated that illite and hydrous micas
are used synonymously in soil work because it is very difficult to make

distinctions within the hydrous mica group. Muscovite and biotite give sharp 10 $\overset{\text{o}}{\text{A}}$ peaks while illite hydromuscovite and hydrobiotite give a broad band of 10-11 $\overset{\text{o}}{\text{A}}$ peaks upon x-ray diffraction (Warshaw and Roy, 1961).

The importance of illite for supplying potassium depends upon the amount of mineral present and the amount of weathering it has undergone (Pratt, 1951). Illite has been reported (Grim, 1953) to be a clay mineral commonly present in soils. It releases less potassium than biotite or muscovite (Reitemeier, 1951; Jackson and Sherman, 1953; Mortland et al., 1957; MacLean and Brydon, 1963). DeMumbrum and Hoover (1958) found that illite released large quantities of potassium following drying. Other researchers have reported that the pure illite mineral is a good source of potassium (Reitemeier, 1957; Gardner, 1960; MacLean and Brydon, 1963). Gardner (1960) and Arnold (1962) found the amount of illite in the soil was not related to the potassium releasing power of soils. Although hydrous micas (Reitemeier, 1951) are important in soil potassium relationships, their identification, estimation and behaviour in soils are unsatisfactorily known. This difficulty arises from differences in potassium content due to weathering, presence of small particles of muscovite and biotite, dissimilarity of illites present in soils, and occurrence of mixed layer minerals.

Alberta soils contain small amounts of illite in the fine clay fraction (< 0.2 μ) while it is the major clay in the coarse clay fraction (2.0-0.2 μ) (Gravenor and Bayrock, 1961; Pawluk, 1961). Pawluk (1961) found the light mineral fraction (sp. gr. < 2.70) to contain potassium feldspars while the intermediate mineral fraction (sp. gr. 2.70 - 2.96) contained muscovite and biotite. However, no quantitative measures were given.

(b) Fixed Potassium

It has been established that most soils possess the ability to fix applied potassium into non-exchangeable forms, the amount fixed will vary with soils and conditions. Mitra et al. (1958) stated that illite fixed more potassium under moist conditions than bentonite or kaolinite. Marshall and McLean (1947) reported illite fixed potassium upon both air and oven drying. Stanford (1947) and Richards and McLean (1963) reported that under moist conditions micaceous minerals fixed potassium and drying further increased the amount fixed. DeMumbrum and Hoover (1958) added potassium to illite at the rate of 10 me./100 g. and found that no fixation occurred even upon drying the illite but that release of potassium took place. Partially weathered or degraded illite can fix potassium strongly (Brown, 1954; Marel, 1954), whereas pure illites do not fix appreciable amounts (Agarwal, 1960). Other hydrous micas, lower in potassium content have high fixing capacities. The mica minerals like muscovite and biotite and the potassium feldspars do not fix potassium (Schuffelen and Marel, 1955). Wiklander (1954), however, stated biotite and muscovite can fix potassium whereas the feldspars can not.

Montmorillonite fixed potassium upon air and oven drying (Marshall and McLean, 1947; Stanford, 1947) while Mitra et al. (1958) reported it fixed potassium under moist conditions. The fixation of more potassium by montmorillonite if the clay was saturated with potassium ions and dried than with wet fixation was reported by Raney and Hoover (1947) and Agarwal (1960). Richards and McLean (1963) in contrast reported that bentonite fixed more potassium in suspension than by air drying. Potassium was found to be released from bentonite which had been stored in a moist condition and to which no potassium had been added.

Marshall and McLean (1947) and Raney and Hoover (1946) reported kaolinite could not fix potassium, while Mitra et al. (1958), and Agarwal (1960) disagreed and stated that small amounts can be fixed. Richards and McLean (1963) found that potassium fixation by kaolinite was absent or insignificant under moist storage, air drying or oven drying.

Kunze and Jeffries (1953) reported that x-ray results indicated clays showing strong 10 $\overset{o}{A}$ lines when saturated with potassium ions and a strong 14 $\overset{o}{A}$ line when saturated with a divalent cation were high fixers of potassium; while those with little or no change in the basal spacing toward 10 $\overset{o}{A}$ when saturated with potassium were low fixers. DeMumbrum and Hoover (1958) reported vermiculite fixed large amounts of potassium upon air drying. DeMumbrum (1958) suggested that vermiculite formed by weathering caused most of the potassium fixation in several Mississippi soils, since the unweathered chalk did not fix potassium. Richards and McLean (1963) found vermiculite fixed more potassium than other clays when air or oven dried. Yet they observed it fixed even less potassium than kaolinite when left in suspension.

Potassium Fixation

The clay fraction of the soil is primarily responsible for potassium fixation (Kardos, 1955). The amount of fixation occurring in a soil will depend on many factors and those believed to be of greatest importance are discussed in this section.

(a) Mechanism of Fixation

Gorbunov (1936, reported by Marel, 1954), postulated that potassium was fixed when potassium ions were pressed into the Helmholtz-Stern double layer as the soil particles dried. Humus does not fix added potassium when dried through it has a well-developed double layer (Jones, 1947). Organic matter added to the soil only competes with the inorganic fraction for exchangeable cations thus reducing the amount of potassium fixed.

Volk (1934) concluded from x-ray analysis of soil fertilized for 50 years that there was an increase in muscovite-like components in the clay fraction as compared to the same fraction from a check plot. This has not received much favour (Agarwal, 1960) due to the fact that muscovite is a hydrothermal mineral not likely to form under field conditions. It is likely, however, that some potassium was restored in the superficially weathered mineral. Volk (1934) and York (1949, reported by Agarwal, 1960) considered fixation under alkaline conditions to be the result of formation of a type of potassium-alumino-silicate in which potassium was fixed. Volk (1938) also found that the addition of $Al(OH)_3$ to the soil increased potassium fixation.

Wear and White (1951) considered that fixation is the result of relatively strong forces at the clay surface arising from the tetrahedral layer negative charges rather than weaker ones from the octahedral negative charges. The negative charge in the tetrahedral layer is usually caused by substitution of aluminum for silica. The distances between potassium ions and sites of negative charges were calculated as 2.19 Å and 4.99 Å for the tetrahedral and octahedral layers respectively. They found illite and vermiculite clays to have relatively more tetrahedral charges than the magnesium-saturated montmorillonite clay. This negative valence in the tetrahedral has a strong binding force for ions which have high polarizability like potassium. Barshad (1954) however, stated that the magnitude and not the source of the charge is the important factor in determining interlayer potassium fixation. It has been found that fixation of potassium by clay minerals results in a reduction in the exchange capacity approximately equivalent to the fixation value (Martin et al., 1945; Wiklander, 1954; Page et al., 1963).

Page and Baver (1940) related the fixation of potassium to the size of the unhydrated ions. They showed that not only potassium ions but ammonium, rubidium and barium ions could be fixed. These all have similar unhydrated ionic radii of 2.66 $\overset{o}{A}$ for potassium, 2.96 for ammonium and rubidium and 2.70 $\overset{o}{A}$ for barium (Kardos, 1955). Ions with diameters which allow them to fit into the voids between hexagonal nets of oxygen ions in the crystal lattice structures of clay should be held tightly because they are close to the negative charges within the crystal. Those ions with approximately the same diameter as the hexagonal opening (2.8 $\overset{o}{A}$) would allow the layers to come together and prevent rehydration. Smaller ions would not be able to bind the layers together while larger ions, unable to enter the opening, would remain loosely bound. This contraction of layers of clays when potassium is introduced caused Barshad (1954) to postulate that the critical basal spacing is 12 $\overset{o}{A}$, below which the displacing ions are unable to remove ions from between the layers of the crystal lattice. Potassium saturated material has a basal spacing of 12 $\overset{o}{A}$ while calcium and magnesium saturated samples have basal spacings greater than 12 $\overset{o}{A}$.

The foregoing reasoning of Page and Baver, regarding the fitting of ions into voids, was based upon the assumption that potassium fixation occurs only when the soil clay minerals of 2:1 expanding type are dried. However, this has been somewhat refuted because large amounts of potassium maybe fixed under moist storage (Stanford, 1947; Mitra et al., 1958; Agarwal, 1960; Richards and McLean, 1963). Furthermore, Martin et al. (1945), Stanford (1947) and Richards and McLean (1963) found clays with non-expanding lattices such as illite may fix potassium in the moist state.

Schuffelen and Marel (1955) postulated from a review of the literature

that more than one type of fixation can occur in the soil. They were: the contraction of lattices and the fitting of potassium ions into the hexagonal oxygen cavities, the formation of potassium-alumino-silicates, the holding of potassium solely by strong tetrahedral charges and the restoration of superficially lost potassium from the potassium minerals. More than one type of fixation has also been reported by Attoe (1946) and McLean and Simon (1958), who found differences in the strength with which moist and dry fixed potassium ions were held.

(b) Factors Affecting Fixation

Wood and DeTurk (1942) and Wiklander (1954) stated that potassium fixation and release proceeds from the edges towards the center of the particles. Fixation in moist soil is thus relatively rapid to begin with and becomes slower as the equilibrium point is approached (Martin et al., 1945; Stanford and Pierre, 1946; York et al., 1953).

The concentration of added potassium will affect both the rate and capacity of fixation. Amounts of potassium fixed increased with the rate of application but the percentage of the total fixed decreased at the higher rates (Volk, 1934; McLean and Simon, 1958). Therefore, a soil which does not fix potassium at a certain concentration may fix it at a higher concentration (Wiklander, 1954).

Drying usually increases fixation because of the increase in potassium concentration and it facilitates lattice contraction (Wiklander, 1954). Repeated wetting and drying was found to increase the soil capacity to fix potassium (Volk, 1934; Martin et al., 1945). Attoe (1946) reported that air drying and moistening may cause either fixation or release depending on whether the initial level of exchangeable potassium was high or low.

Early investigators concluded that potassium fixation in soils and clays was affected by pH. Volk (1934) and Stanford and Pierre (1946) found that leaching the soil with acid prior to adding potassium destroyed the fixing capacity. Martin et al. (1945) reported that at pH 3 the fixing capacity was destroyed and restoration of the soil to the original pH did not return the fixing capacity to normal. This was explained as a result of fixation of H_3O^+ , which has a similar size to potassium (Stanford and Pierre, 1946), in the interlayer positions or by the dissolution of the lattice surface (Wiklander, 1954). The addition of Na_2CO_3 or $CaCO_3$ to soil greatly increased the fixing capacity (Volk, 1934; Martin et al., 1945; York et al., 1953). Stanford (1947) attributed this increased fixation to ease of replacement of calcium, magnesium and sodium by potassium in calcareous soils over ease of replacement of hydrogen, iron and aluminum in acid soils. In recent work Page and Ganje (1964) suggested that since the exchange sites associated with interlayer spaces of expanding clay minerals are due to lattice composition, no direct effect of pH on potassium fixation should be expected. Any change in fixation produced by pH changes would be due to: mineral alteration, the blocking of fixing sites by iron or aluminum complexes, the prevention of lattice collapse as a result of entry of iron or aluminum hydrous oxides or some combination of these. They reported fixation of potassium was independent of pH as long as the concentration of aluminum in the system was kept low. Difficultly replace-able aluminum on the exchange sites or aluminum hydroxides between the lattice of soil particles prevented the adsorption of potassium on sites capable of fixing it. The same was also found true for vermiculite.

The presence of other cations could have a marked influence on the
fixation of potassium. Ammonium and potassium fixation are closely related
and are believed to be fixed by the same mechanism (Stanford and Pierre, 1946).
Welch and Scott (1961) found that additions of ammonium blocked the fixation
or release of potassium if it was added to soil first. Wiklander (1950)
repeatedly treated illite and biotite with the chlorides of hydrogen, ammonium,
sodium, magnesium, calcium or barium in order to release potassium and to
saturate the material with these cations. Potassium was then added and the
material heated. The fixation of potassium was slight or none at all in the
hydrogen and ammonium saturated material, whereas it was high when the material
was saturated with sodium, magnesium, calcium or barium. The H_3O^+ and NH_4^+
having similar radii and valence as the potassium ion were able to compete
for the interlayer positions (Wiklander, 1950; Agarwal, 1960).

Measurements of Potassium Availability

If the magnitude of exchangeable potassium in the soil is changed by
plant removal, it will tend to be restored by movement from the other
forms. Cropping might reduce the exchangeable potassium to a level where the
vigor and health of the plant depends upon the rate of potassium release from
non-exchangeable forms. Since plant roots do not contact all soil particles,
a small amount of soil must supply the nutrient making the release of non-
exchangeable potassium important in supplying the plant needs (Mortland, 1961;
Eagle,1963). The capacity of soils to supply potassium is not easily deter-
mined because of the reversible transformations from one form to another in
soils. Nevertheless, numerous biological and chemical methods have been used
in attempting to determine the potassium availability to plants from exchange-
able and non-exchangeable forms.

(a) Biological

Quick biological methods have been set up to determine the availability of potassium in the soil. The Neubauer test, consisting of growing 100 seeds for 2 or 3 weeks in 100 g. of soil under controlled conditions, has been used to some extent (Kohnke, 1937; McGeorge, 1946; Reitemeier et al., 1947; Bishop et al., 1954). In some reports (McGeorge, 1946; Bishop et al., 1954) it was found closely correlated with yield, while other workers found the correlation was poor to fair (Reitemeier et al., 1947; DeMent et al., 1959). Reitemeier (1951) upon reviewing the literature concluded that the Neubauer value was closely correlated with the initial exchangeable potassium values and the seeds removed little non-exchangeable potassium. Another method of short period cropping has been introduced to determine the availability of potassium (DeMent et al., 1959; Scott and Welch, 1961). Seeds are started in sand cultures deficient in potassium and the plants are transferred to 100 g. of soil for 5 to 10 days. DeMent et al. (1959) and Scott and Welch (1961) found large amounts of potassium were absorbed with differences in uptake from different soils as much as 3.9 mg. of potassium.

Continuous cropping in the greenhouse is regarded by many workers as the best evaluation of the amount of non-exchangeable potassium extracted by plants from a soil (Rouse and Bertramson, 1949; Laws, 1962). This technique is time consuming making it impractical for including a sufficient number of soils to establish precise values for potassium supplying power. However, greenhouse experiments enable the researcher to determine the relationship between the potassium extracted by different chemical methods and that extracted by continuous cropping. Greenhouse experiments have shown that the amount of potassium removed by plants decreases after the first crop (MacLean et al., 1955). The reduction of exchangeable potassium is more rapid in some soils

than in others and the former shows greater response to potassium fertili-

zation. However, the potassium removed by plants becomes constant after two

or three crops (Ayers et al., 1946; Rouse and Bertramson, 1949; MacLean et al.,

1955) and represents the potassium supplying power of the soil. MacLean et al.,

(1957) showed that the higher the potassium content of the crop grown with-

out potassium fertilization, the lower was the yield increase from applied

potassium. Even if no yield increase results, an increase in the potassium

uptake by plants often occurs from potassium fertilization and is referred

to as luxury consumption.

(b) Chemical

(i) Exchangeable. Exchangeable potassium is usually determined

by extracting the soil with neutral N NH_4Ac (Bishop et al., 1954; MacLean

et al., 1957; Scott and Welch, 1961; Laws, 1962). Merwin and Peech (1950)

found that NH_4Ac gave a clear separation of the exchangeable from the non-

exchangeable potassium because only the exchangeable potassium was removed

due to the ammonium ion blocking the release of non-exchangeable potassium

(Welch and Scott, 1961). A correlation between exchangeable potassium in

soils and availability to plants has been cited by several workers. Some

have found a relationship between exchangeable potassium and the uptake

of potassium by plants in the greenhouse (Evans and Simon, 1949; Bishop

et al., 1954; MacLean et al., 1957; Pope and Cheney, 1957; Smith and Matthews,

1957; Sutton and Seay, 1958; MacLean, 1961), while others have reported

a correlation between exchangeable potassium and plant response to potassium

fertilization in the greenhouse (Pope and Cheney, 1957; McLean and Simon,

1958; Jones et al., 1961; Richards and McLean, 1961). Matthews and Sherrell

(1960) found yield responses to fertilizer under field conditions were

correlated with exchangeable potassium for potatoes but not for wheat,

oats or corn. In field trials, Halstead and Heeney (1959) found responses

related to exchangeable potassium on sandy loam soils but not on loam or

clay loam soils. Evans and Simon (1949) stated that small differences

in the exchangeable potassium content of different soils usually represented

much larger differences in their release of non-exchangeable potassium.

Scott and Welch (1961) and Torstensson (1963) reported little relationship

between the exchangeable potassium and the potassium supplying power of soils.

Soils with the same exchangeable potassium values supplied different amounts

of potassium to plants due to differences in texture (Torstensson, 1963).

Laws (1962) found no yield response in the greenhouse to potassium fertilizer

on soils which the NH_4Ac values had indicated would respond. Reitemeier

(1951) stated that in order for exchangeable potassium to be a good indicator

of potassium supplying power of the soil, the different forms of potassium

must be in equilibrium with each other. Pratt (1951) found where exchangeable

potassium served as a good criterion of potassium release to crops over long

periods of cropping, the soils were not strongly weathered. The exchangeable

potassium in strongly weathered soils was low and served as a poor criterion

of potassium release to crops because the portion of potassium used by crops

from the non-exchangeable forms was much higher. In strongly weathered soils,

the rate of release was lower than in slightly weathered soils, furthermore

in these highly weathered soils fertilizers had been added which upset the

equilibrium (Smith and Matthews, 1957), thus the exchangeable potassium was

probably far from the equilibrium level (Pratt, 1951) making exchangeable

potassium values invalid for estimating the supplying power of the soil.

The use of exchangeable potassium is further complicated by the following

facts: only a portion of the exchangeable is removed by the plants due to

incomplete contact, soil solution potassium is included in the exchangeable, release and fixation occur simultaneously in soils and plants differ in their ability to extract exchangeable and non-exchangeable potassium (Reitemeier, 1951).

(ii) Non-exchangeable. It is known plants may obtain substantial amounts of potassium from non-exchangeable forms. Various methods are used to measure the soils ability to supply potassium from these forms. Among them are extraction with strong acid, exchange resin, electrodialysis, and continuous leaching.

The method most frequently employed to determine the potassium supplying power of soils is the strong acid extraction. The extraction of potassium from the soil with boiling N HNO_3 (Reitemeier et al., 1947) has been extensively used. The difference between the total potassium extracted by this method and the exchangeable potassium has been used as the amount of non-exchangeable potassium which slowly becomes available to plants (Hunter and Pratt, 1957). The correlation of potassium removed by boiling HNO_3 to that removed by cropping has varied. A close relationship was found between the potassium extracted by boiling HNO_3 and potassium uptake by cropping in the greenhouse (Rouse and Bertramson, 1949; Pope and Cheney, 1957; Hunter and Pratt, 1957; MacLean et al., 1957; MacLean, 1961). High correlations were found between the amounts of potassium released from non-exchangeable forms by boiling HNO_3 and cropping (Rouse and Bertramson, 1949; Pope and Cheney, 1957; Hunter and Pratt, 1957). Richards and McLean (1961) found boiling HNO_3 was better able to distinguish soils which had fixed potassium from fertilization in previous years than the other methods they tried. Hunter and Pratt (1957) observed a good correlation between the potassium

levels determined by boiling HNO_3 and crop responses to potassium fertilizer.
McLean and Simon (1958) found variation in correlation between boiling HNO_3
extractable potassium and greenhouse response to potassium fertilization.
Halstead and Heeney (1959) and Laws (1962) found no relationship between the
potassium determined by boiling HNO_3 and yield response to potassium
fertilization. Sutton and Sealy (1958) found that NH_4Ac exchangeable
potassium gave a better estimate of the potassium removed by millet and red
clover than did boiling HNO_3-extractable potassium.

Haylock (1956) found that a single digestion with N HNO_3 extracted
only a portion of the potassium soluble in this reagent. The use of repeated
extractions of the soil with N HNO_3 was proposed which would extract non-
exchangeable potassium at a rate characteristic of the soil. In order that
a homionic substrate be extracted the exchangeable potassium was removed by
soaking with 0.01N HNO_3 and then filtering before the first extraction. If
ammonium salts were used to extract the exchangeable potassium, subsequent
removal of non-exchangeable potassium by the first N HNO_3 extraction was
reduced up to 1.5 me./100 g. of soil. Five extractions with boiling N HNO_3
were required to determine the rate of release. The first extraction removed
more potassium than any other, with the amount being nearly constant after
the third extraction. Haylock concluded from this that two forms of non-
exchangeable potassium exist in soil. One of limited solubility extracted
at a constant rate. The other being highly soluble was largely removed
in the first extraction and all removed by the first three extractions. By
extensively cropping the soil and then extracting with N HNO_3, Haylock found
the amount of highly soluble non-exchangeable potassium was reduced but no
reduction in the amount of limited soluble potassium occurred.

Leaching techniques to evaluate the release of potassium have been used by several workers. Mortland (1958; 1959) used 0.1N NaCl to leach lattice potassium from biotite and fixed-potassium from vermiculite in studying the rate of release from these sources. Matthews and Smith (1957) leached soil with very dilute acid at a rate of 5 liters per day and concluded that the slope of the cumulative potassium curve after 17 hours of leaching should be an index of the potassium supplying power of soil. McEwen and Matthews (1958) used CO_2-saturated water for leaching and found the rate of release was constant after 36 hours of leaching. McEwen and Matthews also reported that potassium fertilization in the field or intensive cropping in the greenhouse caused no change in the constant rate of release. They concluded that potassium supplying power was a constant characteristic for each soil. Garman (1957) and MacLean (1961) used 0.01 N HCl for leaching. The latter reported 1 litre removed amounts of potassium equal to the exchangeable and that after 4 litres the rate of removal was nearly constant. Garman (1957), Matthews and Smith (1957) and MacLean (1961) found amounts of non-exchangeable potassium removed by leaching to be correlated with amounts of non-exchangeable potassium taken up by continuous cropping in the greenhouse.

Exchange resins for measuring plant available potassium have been used by some workers (Haagsma and Miller, 1963; MacLean and Brydon, 1963). Schmitz and Pratt (1953) and MacLean (1961) found the non-exchangeable potassium removed from soils by H-resin was correlated with that taken up by plants. MacLean (1961) stated that H-resin removes the relatively accessible non-exchangeable potassium from soils which is the more soluble fraction extracted by boiling N HNO_3 method (Haylock, 1956).

Electrodialysis is another method used to determine the potassium
supplying power of the soil. Ayers (1946), Reitemeier et al. (1947)
and Reitemeier (1951) stated that treatment for 1 to 4 days removed an
amount equivalent to the exchangeable fraction. There is then a subsequent
reduction in the release rate for 10 to 20 days until nearly a constant
rate of release is reached. Reitemeier et al. (1947) found a high correla-
tion between the amount released on dialysis and that released during
cropping in the greenhouse.

There are certain disadvantages to using the foregoing extraction
methods. Acid extraction and electrodialysis are similar in that decomposition
of minerals could occur when the soil is hydrogen saturated. Reitemeier
(1951) stated the breakdown of minerals is usually visible. This acidity
presumably results in the release of potassium due to crystal structure
breakdown. In weathered soils with low potassium supplying power the correla-
tion between yields and potassium extracted by acid methods is usually
poorer than for less weathered soils with high supplying power. This is
because strong acids extract more non-exchangeable potassium than plants
from the former due to the breakdown of the minerals by the acid (Reitemeier,
1951). The use of resin or electrodialysis has the disadvantage of length
of time required for extraction, which can vary from a week to more than a
month. Leaching requires a large volume of leachate to determine the rate
of release.

MATERIALS AND METHODS

Soils

Soils from 11 sites in Alberta, representing 7 soil Sub-Groups were used in the course of the study. The sites were located in the Black, Dark Grey Wooded and Grey Wooded zones of Alberta. The site locations and classification[1] of the soils are presented in Table I. The soils, with the exception of Winterburn, tested below 50 lb./ac. of soil potassium as determined by the 0.024N HAc method in the Alberta Soil and Feed Testing Laboratory. The soils have been described in detail by Bowser et al. (1962).

The Peace Hills series is developed on alluvial material over a solonetzic till[1]. At the Chubocka site on Grey Wooded soil tending toward solod, the upper part of the profile was gleyed. The bedrock was relatively close to the surface at the Chubocka and Sereda sites[1]. The Angus Ridge series at the Wulff site had strong structure with fairly dark color and was tending toward solod.

The parent material of the region is till largely derived from the Edmonton formation which varies in depth. Post glacial sorting occurred in much of the area, therefore local areas of lacustrine, alluvial and deltaic material are also present (Bowser et al., 1962).

Two soil profiles of the Tolmie series were obtained from Vancouver Island. These were developed on marine materials underlain by marine or glacial till and belong to the Dark Grey Gleysolic group (Day et al., 1959). Also the surface 0-6 inch depths of the Burford, and Guelph series were obtained from Ontario. The former was developed on gravelly, calcareous out-wash and is classified as Grey-Brown Podzolic; and the latter series, was

[1] Personal communication with T. W. Peters.

Table 1

The location and classification of soils used for greenhouse, field and laboratory study

Site	Cooperator	Land description	Soil order	Sub-group	Soil series	Parent material
1	A. Adam	SE 25-47-25-4	Chernozemic	Orthic Black	Peace Hills	Alluvial
2	J. Blondheim	SW 18-48-26-4	Chernozemic	Eluviated Black	Angus Ridge	Glacial till
3	C. Murphy	NE 35-48-27-4	Chernozemic	Eluviated Black	Angus Ridge	Glacial till
4	E. Chubocka	SW 2-49-27-4	Podzolic	Grey Wooded	-	Glacial till
5	B. Pearson	NW 32-48-27-4	Gleysolic	Humic Eluviated Gleysol	-	Sorted till
6	N. Byer	SE 3-57-26-4	Solonetzic	Black Solodized Solonetz	Camrose	Glacial till
7	A. Wulff	SE 14-56-26-4	Chernozemic	Eluviated Black	Angus Ridge	Glacial till
8	T. Sereda	NW 10-50-26-4	Solonetzic	Thin Black Solod	-	Sorted till
9	F. Bérubé	SW 29-50-24-4	Solonetzic	Black Solodized Solonetz	Wetaskiwin	Lacustrine
10	A. W. Adam	NE 25-47-25-4	Solonetzic	Black Solodized Solonetz	Camrose	Glacial till
11	H. Evjen	NW 32-51-1-5	Chernozemic	Orthic Dark Grey	Winterburn	Pitted deltaic
12	Experimental Farm Area A	Vancouver Is., B.C.	Gleysolic	Dark Grey	Tolmie	Glacial till or marine clay
13		Ontario	Podzolic	Grey-Brown	Burford	Gravelly outwash
14		Ontario	Podzolic	Grey-Brown	Guelph	Glacial till

developed on loamy glacial till, and is classified as Grey-Brown Podzolic (Matthews et al., 1957).

Greenhouse Study

Soil from 4 sites namely: T. Sereda, H. Evjen, A. W. Adam, and F. Bérubé, representing four soil series were collected in the fall of 1962 (Table 1). Samples (0-6 inch depth) were taken and bulked for each site, passed through a shredder, then through a 0.5 cm. mesh screen, mixed and potted. An equal weight of soil (1360 g.) was put in all pots. Three crops of barley and four cuts of alfalfa were grown in sequence. The pots were brought up to 1/3 atmospheric moisture (by weight) with distilled water once a week and between weighing were watered when visual inspection indicated the need.

Gateway barley, treated with Cerosan, was seeded (20 seeds per pot) and after 10 days thinned to 12 plants per pot. It was harvested when the best stand was in the shot blade stage. The experiment with barley was started on November 4, 1962, and terminated April 1, 1963. Grimm alfalfa seeds were placed on filter paper in petri dishes, moistened, sprinkled with "Nitragin AB" legume inoculant and allowed to germinate. Ten seedlings were planted April 5, 1963 and thinned to six per pot 10 days later. Four cuts were taken when the best stand was approximately 10 per cent in bloom. Plants were harvested by cutting approximately one half inch above the soil surface. Cuttings of both the barley and alfalfa were dried overnight in an oven at 65° C and weighed. The fourth alfalfa cutting was taken January 4, 1964 at which time the pots were emptied, the roots and nodules examined and composite soil samples taken of each treatment.

The treatments replicated six times were 0, 30, 60, 120 lb./ac. of K. A blanket application of 20 lb. of N and 40 lb./ac. of P was added to all treatments. The nitrogen, phosphorus and potassium were applied in solution as NH_4NO_3, $Ca(H_2PO_4)_2$. $2H_2O$, and KCl respectively to the soil surface prior to each cropping.

Field Experiments

Soil potassium values (Alberta Soil and Feed Testing Laboratory) were plotted on a map of Alberta and it was evident that rather large areas, mainly surrounding Edmonton, had values less than 50 lb./ac. Tentatively, these values are regarded as being low. Several field sites with low values were examined in these areas and nine were chosen for field studies. The test sites were located on stands of clover or alfalfa, since legumes require larger quantities of potassium than do cereals. The experimental design was a 3 x 3 x 3 factorial replicated twice with six sub-blocks. The design was used to test the response to potassium, nitrogen, phosphorus, and their interactions. The plots size was 3 1/2 ft. by 30 ft. The 27 treatments consisted of 3 levels of potassium at 0, 25, and 50 lb./ac. of K, three levels of nitrogen at 0, 20 and 40 lb./ac. of N, three levels of phosphorus at 0, 13 and 26 lb./ac. of P, and all possible combinations of these. The K was applied as muriate of potash (0-0-60), the N as ammonium sulfate (21-0-0), and the P as triple superphosphate (0-45-0).

The plots were harvested in the early bloom stage. Green weights were recorded in the field and samples were taken for moisture analysis in order to convert yields to oven dry weight basis. Samples of alfalfa were collected from selected plots for potassium analysis. Three to 4 inches of terminal growth from plants just starting to bloom were sampled to ensure that all plants were at the same physiological stage of growth. Some 100 to 125 g. of green weight material were collected at random from each plot to give approximately 25 g. of dry material.

Laboratory Study

Soil samples were collected with a "Bull" soil coring machine during the first week in July, 1963. Only the major horizons were sampled with

separations made on the basis of differences in color, texture and structure. The samples were air dried and passed through a 2 mm sieve.

(a) Chemical Analyses

The important features of the methods will be outlined. The pH values of the soil pastes were measured using a Beckman model H-2 pH meter, equipped with a glass and a calomel electrode (U.S.D.A. Handbook 60, 1954). Exchangeable cations were extracted from the soil samples with neutral 1N NH_4Ac solution (Atkinson et al., 1958). The exchangeable calcium and magnesium were determined by the ethylenediaminetetracetic acid method (U.S.D.A. Handbook 60, 1954).

The cation exchange capacity was determined by the method outlined in A.O.A.C. (1955), which is the extraction of adsorbed ammonium with normal sodium chloride solution and determination of the ammonia content by the magnesium oxide method.

Nitrate nitrogen was determined as outlined by Spurway and Lawton (1949). To five grams of soil was added 25 ml. of 0.024N HAc, then shaken for 2 minutes and filtered. The nitrate in the filtrate was determined with diphenylamine solution. Phosphorus determination was made following the Kitson and Mellon (1944) method of using an extracting solution containing 0.03 N H_2SO_4 and 0.03 N NH_4F. The color, developed by adding 5 ml. each of, 5N sulfuric acid, 0.25 per cent ammonium vanadate, and 5 per cent ammonium molybdate in succession was read in an electrophotometer.

(b) Potassium Determinations

(i) Exchangeable. The exchangeable potassium in the 1N NH_4Ac extract was determined with a Beckman Model DU flame spectrophotometer. The settings for the potassium determination were: wave-length 769 mu, red

sensitive phototube, load resistor-3, slit width 0.30 mm., acetylene 2.5 p.s.i., oxygen 9.0 p.s.i. Standard potassium solutions were prepared in ammonium acetate. A "radiation" buffer containing 25 me./l. of calcium, 50 me./l. magnesium, and 40 me./l. sodium was added to the standard solutions and soil extracts when readings were taken.

(ii) Spurway. An estimate of available potassium was carried out by the Spurway extraction procedure (Spurway and Lawton, 1949). The potassium in the 0.024N HAc extract was determined on the Perkin Elmer flame photometer.

(iii) Rate of Release. The rate of release of non-exchangeable potassium was determined by repeated extractions with boiling 1N HNO_3 using slight modifications to that proposed by Haylock (1956), and revised by MacLean (1961) and Goettel (1962). Exchangeable potassium was removed from a five gram sample by soaking overnight in 0.1N HNO_3 followed by 5 subsequent leachings with fresh aliquots of the same acid. The soil and filter paper were then transferred to a 250 ml. electrolytic beaker, 50 ml. of 1N HNO_3 were added with stirring, brought to a boil on a hot plate within 3 minutes, and allowed to boil for 10 minutes at a reduced temperature on a sand bath. The suspension was cooled in a cold water bath and made up to 100 ml. with distilled water; the beakers were previously graduated. The suspension was centrifuged in the beakers for 10 minutes at 1,200 r.p.m. Foam rubber was placed in the bottom of the centrifuge cups, around the upper part of the beakers and water was added between the cups and beakers to prevent breakage. The supernatant liquid was decanted into 4-ounce glass bottles for storage. The procedure was repeated five times. Potassium in the extract was determined using the flame photometer method as stated previously except the standard potassium solutions were prepared in 0.5N HNO_3.

Plant samples were ground on a Christie and Norris mill equipped with a 1 mm. sieve and dry-ashed for 2 hours at 550° C. The residue was dissolved in 10 ml. of 1N HNO_3 and made up to 200 ml. with 0.1N HNO_3. Potassium in the extract was determined with the flame photometer.

(c) Physical Analyses.

The 1/3 atmosphere method for field capacity and the 15 atmosphere method for wilting point (U.S.D.A. Handbook 60, 1954) were used on the soils. Mechanical analyses were performed using the method of Toogood and Peters (1953). Wet sieving was used to separate the sand fraction. The fine clay was separated by centrifuging the clay suspension (Baver, 1959). The percentages were calculated on the oven dry weight of the soil after organic matter and carbonate had been removed.

(d) Mineralogical Analyses

The separation of the soil into particle sizes was done following the method outlined by Jackson et al. (1949) with modifications suggested by Pawluk (1961). Essentially the method included the removal of carbonates, soluble salts and organic matter (Jackson et al., 1949). Dispersion of the particles was done by adjusting the suspension to a pH of 8.0 with Na OH and after allowing the suspension to stand overnight the pH was readjusted (Pawluk, 1961). The top 8 cm. of the suspension were siphoned off following a setting time of 6 hours and 8 minutes, which separated the clay from the sand and silt fractions. The settling time was calculated by Stoke's Law (Baver, 1959). The fine clay was separated from the coarse clay fraction by centrifugation of the foregoing clay suspension for 1 hour and 6 minutes at 1,800 r.p.m. (Baver, 1959).

The clay fractions were flocculated by adding 25 ml. of saturated

calcium chloride followed by washings with distilled water to remove chlorides. Oriented clay films on glass slides were prepared for x-ray analysis by allowing a few drops of suspension to air dry by standing overnight (Kittrick, 1961). The clay samples were glycolated by placing prepared slides in a saturated atmosphere of ethylene glycol in a desiccator at 60° C.[1] Duplicate samples were heated to 550° C. for 2 hours prior to x-ray analysis and stored in a desiccator.

The x-ray unit was a Norelco x-ray diffractometer equipped with a Geiger counter and a Brown recorder. The x-ray unit was set at 35 kilovolts and a current of 15 milliamperes and had a Cu K_{α} radiation with a nickel filter. A scale factor of 4 and a time constant of 8 were used on the recorder with a scanning time of 1 degree per minute. Scanning was done over the range 3 to 30 degrees which is equivalent to 29.42 Å to 2.97 Å.

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[1] S. Pawluk - personal communication.

RESULTS AND DISCUSSION

Greenhouse Study

The yields of 3 barley crops and 4 alfalfa cuts, grown in succession, are shown in Table 2 and for selected data in Figure 1.

(a) Barley Yields.

The first crop of barley on Wetaskiwin soil was destroyed by bacterial wilt[1]. Barley responded to potassium in all soils as the yields were higher in all treatments receiving added potassium as compared to the check yields. Significant responses were obtained for the Thin Black Solod (32 lb./ac. of K[*]) and the Camrose (42 lb./ac. of K) soils for the 60 and 120 lb./ac. of K treatments. Response of barley to all levels of added potassium was highly significant over the check for the two harvests on the Wetaskiwin (22 lb./ac. of K) soil. The Winterburn (104 lb./ac. of K) soil produced slightly higher barley yields due to added potassium but only the 60 and 120 lb./ac. rates for the second crop produced significant increases.

(b) Alfalfa Yields.

The alfalfa was slow getting established on the Thin Black Solod (32 lb./ac. of K) soil. Yields for all treatments progressively increased up to the third cutting and then declined for the fourth. In general, yields were increased for all cuttings by applying potassium at 30, 60 and 120 lb./ac. Highly significant responses occurred for the 60 and 120 lb./ac. of K rate for the first cut and to all 3 levels of potassium in the second and third cuttings. Yields were increased by the potassium treatments for the fourth cut but the amounts were not significant.

The Camrose (42 lb./ac. of K) soil did not respond to added potassium except to the 60 lb./ac. level for the first cut. The yields decreased

[1] Personal communication N. Colotelo, Plant Pathologist. U. of Alberta, Edmonton, Canada.

[*] 0.024N HAc method.

Table 2

Barley and alfalfa yields from greenhouse experiment

(grams per pot, average of 6 replications)

Soil	Treatment[1]	Barley cutting			Alfalfa cutting			
		1	2	3	1	2	3	4
Thin Black	20-40-0	2.3	2.2	2.8	1.6	1.8	3.1	2.5
Solod	20-40-30	2.6	2.4	3.0	1.8	2.2**	4.0**	3.0
(T. Sereda)	20-40-60	2.5	2.8*	3.5**	2.0**	2.4**	4.0**	3.0
	20-40-120	2.9*	2.9**	3.9**	2.1**	2.4**	4.2**	2.8
	L.S.D. .05	0.6	0.5	0.5	0.3	0.3	0.4	0.6
	.01	0.8	0.7	0.7	0.4	0.4	0.6	
Camrose	20-40-0	1.6	3.0	3.0	2.1	2.1	1.7	1.6
(A.W. Adam)	20-40-30	1.8	3.1	3.1	2.2	2.2	1.4	1.4
	20-40-60	1.9*	3.7**	4.0**	2.6**	2.2	1.5	1.3
	20-40-120	1.9*	3.9**	4.0**	2.1	1.8	1.4	1.3
	L.S.D. .05	0.3	0.3	0.4	0.3	0.3	0.3	0.2
	.01	0.4	0.4	0.6	0.4			
Wetaskiwin	20-40-0	-	2.0	2.4	1.6	1.8	1.8	1.7
(F. Bérubé)	20-40-30	-	2.4**	3.5**	2.5**	2.5**	2.4	1.7
	20-40-60	-	2.5**	4.0**	2.6**	2.6**	2.3	1.6
	20-40-120	-	2.7**	4.5**	2.6**	2.5**	3.0*	2.4
	L.S.D. .05		0.2	0.4	0.3	0.4	1.1	0.8
	.01		0.3	0.5	0.4	0.6	1.5	
Winterburn	20-40-0	1.6	2.3	2.6	2.1	1.8	1.6	1.3
(H. Evjen)	20-40-30	1.2	2.5	2.7	2.9**	2.4**	2.0*	1.4
	20-40-60	1.2	2.9**	3.0	2.4*	2.0	1.8	1.2
	20-40-120	1.6	3.0**	3.0	2.4*	1.6	1.2	0.9
	L.S.D. .05	0.4	0.4	0.5	0.3	0.4	0.4	0.2
	.01		0.5		0.4	0.5	0.6	

[1] Treatments applied prior to each cropping.

* Significance at the 0.05 level.

** Significance at the 0.01 level.

progressively for all treatments after the first cut. Added potassium, especially the high rate of 120 lb./ac., appeared to decrease yields in all 4 cuttings while all levels of added potassium appeared to decrease yields in the third and fourth cuttings.

Response to added potassium occurred for the Wetaskiwin soil (22 lb./ac. of K). Growth remained nearly constant for the first 3 cuts and declined for the fourth. Radical variation occurred within the 120 lb./ac. K treatments for the third and fourth cuts for this soil as indicated by the high LSD. Highly significant responses occurred to all levels of added potassium in the first 2 cuts. All levels of added potassium increased yield for the third cutting but only the 120 lb./ac. of K treatment was significant due to the high variability. In the fourth cut the 120 lb./ac. of K treatment produced more than the check yield but not by a significant amount.

Alfalfa yields for the Winterburn (104 lb./ac. of K) declined with each successive cutting within each treatment. The 30 lb./ac. of K treatment produced increased yields of all 4 cuttings and significant increases for the first three. The 120 lb./ac. of K treatment appeared to decrease yields except in the first cutting.

Upon inspection of the soils after the fourth alfalfa cutting it was found that masses of roots were present in all pots for all soils. In the Thin Black Solod all treatments had abundant nodules although there were somewhat fewer in the check treatment and many appeared to be alive. The Camrose soil had no apparent differences in the number of nodules between treatments. However, there was not an abundance of nodules and those present were dry and dead in appearance. Nodules in the Wetaskiwin and Winterburn soils were abundant with no differences between the treatments. Most of the
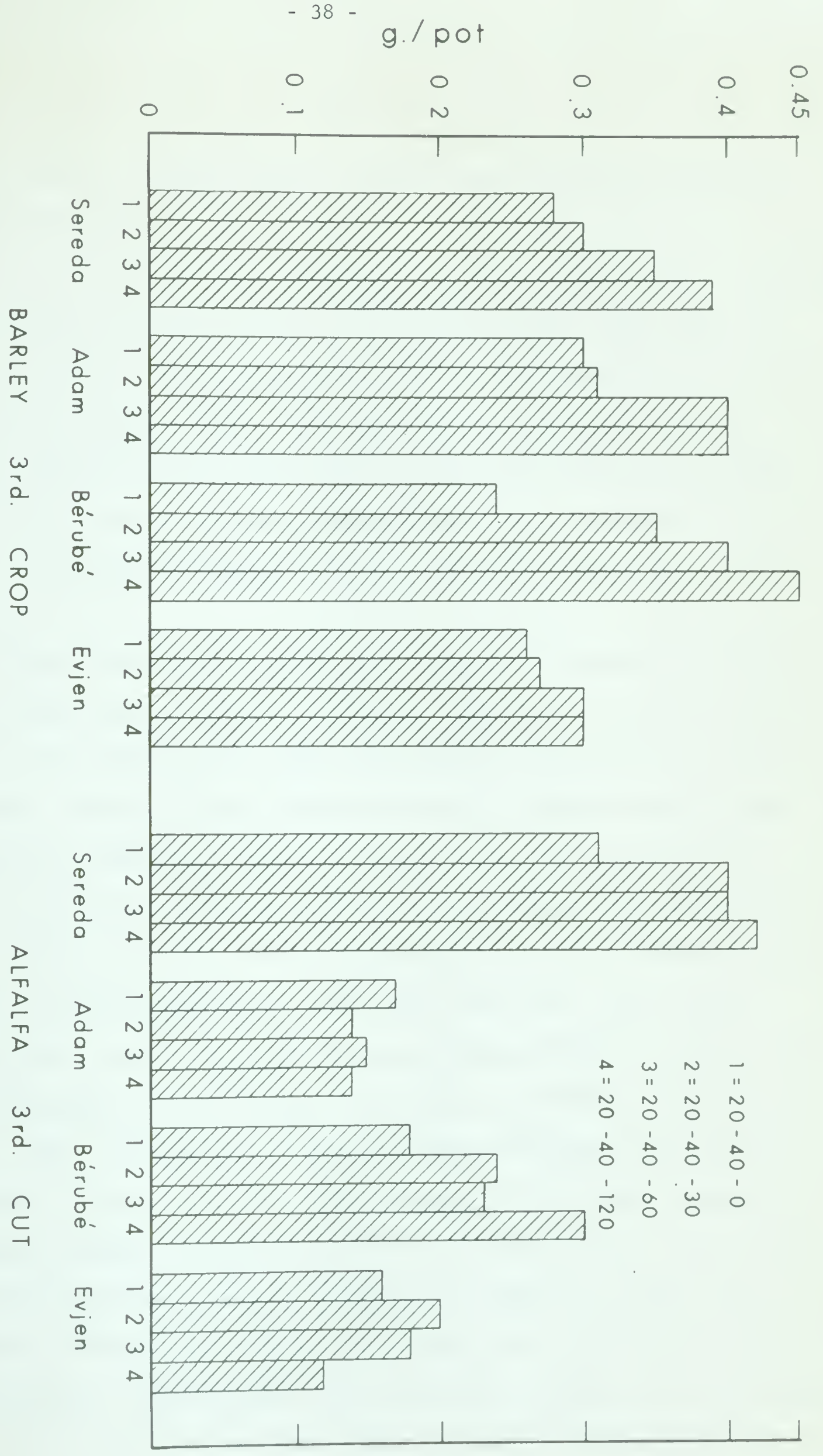
Fig. 1 Yield of barley and alfalfa in greenhouse experiment.

nodules were dry and appeared dead, probably because the soil was quite
dry when inspected.

The alfalfa on all soils appeared to be root bound and this is suggested
as a reason for decreased growth in the later cuttings. The alfalfa in
Thin Black Solod soil was slow in establishing and therefore did not become
root bound as quickly as the other soils, and thus the yields did not
decline until the fourth cutting while crops on the other soils declined
by the third cutting. Another possible reason for a decline is that some
nutrient other than nitrogen, phosphorus or potassium became the limiting
factor.

The greenhouse results showed that responses to potassium application
on soils with test values below 50 lb./ac. (HAc) did occur as depicted in
Figure 1 for selected data. There was a tendency for these soils to give
a slightly greater and more consistent response to added potassium than
the Winterburn which has a higher soil test value (104 lb./ac. of K).
However, greenhouse and field conditions differ greatly and furthermore
only the Aa* horizon was used in the greenhouse study and most plants and
especially alfalfa feed deeper under field conditions. Some research
workers have found that there is little correlation between greenhouse and
field experiments (Halstead et al., 1957; McLean and Simon, 1958; Hanway
et al., 1961), although it is still an accepted technique for evaluating
the potassium status of soils. Halstead et al. (1957) found exchangeable
potassium remained constant with depth in most soils tested. They found
yield and percentage content of potassium were similar in plants grown
in surface and subsurface samples and in some soils they were higher for
the subsurface. Hanway et al. (1961) found less potassium in the subsurface
than surface soil, and also found a poor correlation between uptake of

*
Disturbed by cultivation.

potassium in the field and uptake from the surface soil in the greenhouse

showing that environmental conditions in the field had a marked effect on

potassium uptake by plants in the field. McLean and Simon (1958) obtained

yield responses to applied potassium in the greenhouse, however, no response

occurred in the field. They concluded that complicating factors such as

subsoil feeding and climatic conditions should be sufficient reason to expect

a poor correlation between greenhouse and field response to applied potassium.

Field Experiments

The yields of the hay harvests for 1963 and 1964 are shown in Table 3.

Low yields and poor response to fertilizer in 1963 are attributed to the low

soil moisture, lack of spring rains, and below normal summer precipitation.

Soil moisture at time of fertilization was good for the Aa horizon and fair

for the B and C horizons except at the Chubocka, Byer, Wulff, and Sereda

sites which had only fair moisture in all horizons. No rainfall occurred

on any of the sites, except Pearson, between the time of application and July

1. Rainfall for the season ranged from 3.0 to 5.2 inches, which is below

the normal.

No significant response to potassium fertilization occurred in 1963

except at the Chubocka site for treatment 0-0-50 and this was considered to

be erratic. Significant response to nitrogen occurred at the Pearson and

Murphy sites, and to phosphorus at the Pearson, Blondheim, Murphy, Adam and

Byer sites. No significant interactions occurred at any of the sites.

Assuming N, P and K cost 12, 21, and 6 cents per pound respectively and hay

cost 20 dollars per ton only the Pearson and Murphy sites gave economical

yield responses. Although the N and P effects were significant at the

Murphy site, results were too variable to select any one treatment as being

Table 3

(SEE OVER)

Table 3

Hay yields from nine sites

(tons per acre, average of two replicates)

| Name | B. Pearson | | | A. Wulff | |
| Year | 1963 | | 1964 | 1963 | 1964 |
Treatment	Cut 1	Cut 2	Cut 1	Cut 1	Cut 1
0-0-0	0.49	0.48	0.63	0.43	0.61
0-0-25	0.41	0.53	0.52	0.31	0.46
0-0-50	0.46	0.52	0.46	0.31	0.48
0-13-0	0.68	0.71*	0.72	0.28	0.54
0-13-25	0.63	0.77*	0.76	0.30	0.47
0-13-50	0.62	0.81*	0.85	0.30	0.48
0-26-0	0.62	0.72*	0.72	0.28	0.57
0-26-25	0.60	0.80*	0.79	0.33	0.69
0-26-50	0.56	0.72*	0.76	0.43	0.71
20-0-0	0.60	0.54	0.73	0.40	0.58
20-0-25	0.64	0.63	0.94	0.26	0.68
20-0-50	0.59	0.44	0.68	0.22	0.51
20-13-0	0.72	0.72*	0.82	0.33	0.52
20-13-25	0.75	0.69*	0.81	0.30	0.46
20-13-50	0.88*	0.84*	1.17	0.33	0.60
20-26-0	0.70	0.65	0.89	0.41	0.92
20-26-25	0.69	0.66	0.94	0.35	0.80
20-26-50	0.93*	0.76*	1.02	0.25	0.58
40-0-0	0.75	0.63	0.92	0.29	0.51
40-0-25	0.81*	0.55	0.97	0.26	0.53
40-0-50	0.62	0.68*	0.69	0.42	0.54
40-13-0	0.68	0.66	1.15	0.32	0.79
40-13-25	1.01*	0.61	1.22	0.23	0.59
40-13-50	0.78	0.77*	1.03	0.33	0.66
40-26-0	1.08*	0.80*	1.55*	0.33	0.53
40-26-25	0.81*	0.82*	1.15	0.36	0.86
40-26-50	0.92*	0.81*	1.21	0.30	0.74
L.S.D. - 5%	0.31	0.20	0.70	0.20	0.37

* Significance at 0.05 level.

Table 3 (continued)

| E. Chubocka | | J. Blondheim #1 | | C. Murphy | A. Adam | N. Byer |
| 1963 | 1964 | 1963 | | 1963 | 1963 | 1963 |
Cut 1	Cut 1	Cut 1	Cut 2	Cut 1	Cut 1	Cut 1
0.94	0.64	0.78	0.56	1.35	0.62	0.55
1.26	0.73	0.82	0.63	1.50	0.45	0.56
1.60*	0.78	0.80	0.66	1.62	0.66	0.54
1.03	0.60	0.84	0.58	1.95*	0.63	0.83
1.10	0.69	0.77	0.77	1.88*	0.59	0.65
1.18	0.87*	0.60	0.50	1.76	0.58	0.74
1.17	0.77	0.90	0.60	1.33	0.57	0.57
1.09	0.77	0.80	0.69	1.36	0.74	0.79
1.11	0.74	1.04	0.63	1.44	0.60	0.56
1.14	0.73	0.69	0.60	1.99*	0.51	0.51
1.04	0.62	0.70	0.70	1.47	0.59	0.51
1.04	0.88*	0.65	0.58	1.74	0.59	0.55
1.25	0.73	0.67	0.51	1.90*	0.67	0.70
1.26	0.70	0.82	0.74	1.71	0.55	0.71
1.19	0.78	0.80	0.59	1.90*	0.59	0.75
0.97	0.76	0.83	0.57	1.45	0.67	0.53
1.05	0.74	0.99	0.73	1.54	0.57	1.02*
0.97	0.63	0.92	0.66	2.04*	0.62	1.16
1.39	0.63	0.79	0.56	1.91*	0.74	0.53
1.14	0.78	0.66	0.75	2.05*	0.51	0.50
1.22	0.84	0.88	0.59	1.86	0.54	0.60
1.19	0.72	0.73	0.52	1.90*	0.68	0.58
1.36	0.83	0.74	0.67	2.08*	0.69	0.63
1.32	0.69	0.63	0.51	1.90*	0.60	0.88
1.28	0.62	0.80	0.58*	2.07*	0.65	0.83
1.00	0.82	0.77	0.67	1.37	0.66	0.79
1.03	0.67	0.82	0.73	2.05*	0.67	1.00*
0.52	0.23	0.34	0.29	0.53	0.19	0.43

best economically. The highest net return at the Pearson site from the

two cuttings was $7.94 per acre from the 40-26-0 treatment while the

second best return was $6.87 per acre from the 20-13-50 treatment.

Soil moisture in the spring of 1964 was good in all horizons at the

Pearson site, while at the Chubocka, Wulff, and Sereda sites only fair

moisture was present in all horizons. Rainfall until the first cut in

1964 was well above that of 1963 and near normal for the area. This rainfall,

however, was not sufficient to produce a high yield since the soil moisture

reserve was low.

The sites at Blondheim, Murphy, A. Adam, and Byer were discontinued

in 1964. For the first 2 sites the hay field was being tilled while variability

of stand in the latter 2 sites was the reason for discontinuance. No crop

was harvested at the Sereda site in either 1963 or 1964 because the clover

stand never got above 3 inches in height. The reason for this is unknown

but is apparently due to some cause other than N, P or K.

In 1964 the yields were higher than 1963 due to more precipitation during

the growing season. No significant response occurred to potassium at any of

the sites. However, at the Chubocka site a trend towards increased yields

from potassium fertilizer occurred. Significant response to nitrogen occurred

at the Pearson site and to phosphorus at the Pearson and Wulff sites.

Significant interactions between phosphorus and nitrogen, and phosphorus

and potassium occurred at the Wulff site.

Soil Analyses

Results of the physical and chemical analyses performed to characterize

the soils used in this study are as follows:

(a) Physical.

Mechanical analysis, Table 4, of the soil profiles shows the Aa horizons

differ in texture with sandy loam, loam, silt loam and clay loam classes being represented. The clay content varies from 5 to 31 per cent. Goettel (1962) found clay contents ranged from 17 to 32 per cent in the soils that he studied. The B horizons vary from sandy loam to clay loam with clay contents ranging from 20 to 29 per cent. In the C horizons the texture is mainly loam, with a few sandy loam and sandy clay loam textures. The clay content ranges from 19 to 29 per cent.

The 1/3 atmosphere moisture contents of the Aa horizons range from 16.4 per cent for a sandy loam to 33.3 per cent for a clay loam soil. The range in the B horizons was from 21.6 to 38.8 per cent, for a loam and clay loam respectively. In the C horizon the values for 1/3 atmosphere moisture ranged from 21.7 per cent for a sandy loam to 39.8 per cent for a loam textured soil. The 15 atmosphere moisture percentages follow the same trend as the 1/3 atmosphere, although the values are much smaller. The range was from 5.5 for a sandy loam to 15.9 per cent for the loam C horizon of the Wetaskiwin profile.

(b) Chemical.

The cation exchange capacities of the Aa horizons (Table 4) range from 10.8 (Tolmie) to 36.4 (Gleysol) me./100 g. of air dry soil. The low values occur in the Tolmie, Burford, and Guelph soils which have low clay contents. The high values as often experienced are associated with high clay contents and/or high amounts of organic matter. Goettel (1962) found that the same association occurred. The calcium content increased with depth in the profile with amounts in the C horizon in several profiles exceeding the cation exchange capacity. In the Gleysol the calcium content was higher than the exchange capacity in all horizons indicating the accumulation of lime. The

Table 4

(SEE OVER)

Table 4

Physical and chemical analyses of selected soils

Soil	Horizon	Depth in.	%S	%Si	%C	%0.2uC	Texture
Grey Wooded	Aa*	6	48	38	14	4	L
(E. Chubocka)	B	24	47	28	25	17	L
	C	@ 30	47	33	20	14	L
Humic Eluviated	Aa	8	34	37	29	13	CL
Gleysol	B	16	41	34	25	18	L
(B. Pearson)	C	@ 24	48	32	20	14	L
Angus Ridge	Aa	12	24	45	31	18	CL
(A. Wulff)	B	13	30	41	29	22	CL
	C	@ 25	39	37	24	12	L
Thin Black	Aa	8	32	53	15	4	SiL
Solod	B	14	42	33	25	15	L
(T. Sereda)	C	@ 22	30	46	24	12	L
Wetaskiwin	Aa	6	36	48	16	11	L
(F. Bérubé)	B	11	34	38	28	12	CL
	C	@ 17	38	38	24	14	L
Camrose	Aa	9	64	25	11	8	SL
(A. W. Adam)	B	11	46	28	26	21	L
	C	@ 20	51	20	29	16	SCL
Winterburn	Aa	8	18	62	20	11	SiL
(H. Evjen)	B	@ 8	11	69	20	14	SiL
Tolmie #1	Aa	9	41	40	19	6	L
(Vancouver Is.)	AB	4	37	37	26	23	L
	B	6	27	47	26	21	L
	D	@ 19	40	40	20	12	L
Tolmie #2	Aa	10	66	29	5	2	SL
(Vancouver Is.)	AB	4	38	37	25	20	L
	B	6	42	30	28	14	CL
	D	@ 20	59	22	19	14	SL
Burford (Ontario)	Aa	6	39	46	15	6	L
Guelph (Ontario)	Aa	6	60	35	5	4	SL

* A horizon disturbed by cultivation.

Table 4 (continued)

% moisture		Exchange	Exchangeable		0.024 N H Ac	0.03N NH$_4$F 0.03N H$_2$SO$_4$	
		(me./100 g. air dry soil) 1N NH$_4$Ac			(me./100 g. air dry soil)		
1/3 Atmos.	15 Atmos.	capacity	Ca^{++}	Mg^{++}	Nitrate	Phosphorus	pH
24.0	7.2	16.9	12.0	2.4	.04	.17	6.2
27.5	10.6	16.1	9.4	4.5	.03	.10	7.3
28.6	9.6	14.2	24.0	5.6	.06	.00	8.5
32.1	15.7	36.4	37.6	5.7	.04	.01	7.5
21.6	9.3	16.4	22.0	4.6	.03	.00	7.6
25.0	9.6	16.6	17.9	4.3	.03	.00	7.4
33.3	11.6	35.4	25.0	7.8	.01	.01	6.5
30.8	9.5	31.3	20.6	10.8	.03	.00	7.1
23.6	11.6	16.5	33.1	7.9	.01	.00	7.8
25.7	7.2	20.1	11.7	3.3	.03	.04	6.3
29.3	11.5	22.2	14.3	6.4	.04	.00	7.4
39.8	15.4	27.5	28.1	8.5	.03	.00	7.5
30.5	14.8	21.5	10.3	3.0	.07	.02	5.6
38.8	15.9	24.2	11.5	7.6	.00	.00	7.3
28.6	13.8	18.7	32.3	7.6	.00	.00	7.7
20.2	11.7	18.1	8.0	2.6	.05	.03	5.9
28.2	12.6	20.0	11.6	5.7	.01	.00	7.4
36.4	13.7	18.6	29.9	6.3	.00	.00	8.4
20.8	9.0	26.8	21.4	3.6	.00	.05	6.8
32.1	11.1	21.8	15.4	5.2	.00	.00	6.6
24.7	8.7	14.1	8.6	1.5	.04	.02	5.7
22.9	12.1	15.8	10.1	3.1	.03	.00	6.0
29.7	12.9	18.9	16.2	6.3	.03	.00	6.5
23.8	8.7	17.1	14.0	5.1	.03	.00	6.6
17.7	6.4	10.8	4.8	0.7	.03	.03	5.7
22.8	11.3	16.4	3.7	0.9	.03	.01	5.9
24.3	11.3	15.2	12.6	5.1	.03	.00	6.1
21.7	9.4	15.4	12.9	4.5	.03	.00	6.1
22.0	6.3	13.6	11.6	2.6	.04	.16	7.5
16.4	5.5	11.1	11.3	0.0	.04	.04	7.3

reaction of the horizons also reflects the calcium content. The surface

horizons were slightly acidic, with pH values from 5.6 to 6.8, except for

the Gleysol, Burford, and Guelph soils which were basic. The pH increases

with depth as the calcium increases and is highest in the C horizons,

where the pH values range from 7.4 to 8.5. The Tolmie profiles do not

contain free lime in any horizon and the pH values are acidic for all

horizons.

The nitrate content varies from an undetectable amount in the Winterburn

soil to 0.07 me./100 g. of air dry soil in the Wetaskiwin. Available

phosphorus values range from 0.01 me./100 g. in the Gleysol and Angus Ridge

to 0.17 in the Grey Wooded. Available phosphorus was detectable only in

the surface horizon except in the Grey Wooded and Tolmie soils.

(c) Potassium Determinations.

Potassium extracted with $1N$ NH_4Ac, $0.024N$ HAc, and $0.1N$ HNO_3 are shown

in Table 5 and for selected soils in Figure 2. The potassium extracted

from the Aa horizon with NH_4Ac is greatest for the Winterburn soil, of all

those tested, with a value of 0.60 me./100 g. of air dry soil. The Grey

Wooded and Angus Ridge had 0.34 and 0.30 me./100 g. while the Burford,

Guelph and two Tolmie soils had the lowest values of 0.08, 0.08, 0.07 and

0 .05 me./100 g. The extractable potassium with NH_4Ac increase with depth

in the profiles except for the Grey Wooded and Winterburn soils. The

saturation percentages increase with depth in the profile except in the Grey

Wooded and Winterburn soils where they are highest in the surface horizons.

Goettel (1962) found for the soils studied that the Aa horizon of the

Airdrie soil had the highest value (around 1.0 me./100 g.) for NH_4Ac

extractable potassium and the highest saturation percentage (around 4.0

per cent). The Angus Ridge soils that he tested gave values of approximately

0.4 me./100 g. NH_4Ac extractable potassium and 1.2 per cent potassium

saturation. He also found the NH_4Ac extractable and per cent saturation

decreased with depth in the Airdrie, while in the Angus Ridge the NH_4Ac

extractable was constant and the per cent saturation increased with depth.

The NH_4Ac extractable potassium differs from that in this study for the

Angus Ridge in that it is slightly larger and does not increase with depth.

However, the saturation percentages increase with depth. The Airdrie

soil is similar to the Winterburn in that both have the highest extractable

and saturation percentages for the surface horizons and these decrease with

depth.

Halstead et al. (1957) and MacLean et al. (1957) found that no response

to potassium fertilizer occurred if the NH_4Ac value of the surface soil

was over 0.30 me./100 g.[*] However, they also found soils with values

less than 0.30 me./100 g. which did not give significant yield increases

to added potassium. Thus the surface NH_4Ac extractable value is not

necessarily indicative of whether the soil will respond to potassium

fertilization. Oregon State College (1958) considers that below 0.19

me./100 g. (NH_4Ac) is very low for clover-grass mixtures and grains. They

found that response occurs from added potassium up to soil test values of

0.45 me./100 g. for clover-grass mixtures and up to 0.26 me. for grains.

In Wisconsin (Anonymous, 1962) below 0.12 me./100 g. (NH_4Ac) of exchangeable

potassium is considered very low for alfalfa crops and response occurs for

soil test values up to 0.26 me./100 g. For Minnesota (Anonymous, 1961)

soil test values below 0.12 me./100 g. (NH_4Ac) of exchangeable potassium

are very low for alfalfa crops and responses occur up to 0.38 me./100 g.

Thus the values vary for different parts of the country but are higher

than the values found for surface horizons of the Gleysol, Grey Wooded,

[*] 1 me. K = 780 lb. of K/ac.

Table 5

Potassium extracted with 1N NH_4Ac, 0.024N HAc, and 0.1N HNO_3

| Soil	Horizon	(me./100 g. air dry soil) NH_4Ac	% K Sat.	HAc	HNO_3
Grey Wooded	Aa*	.34	2.01	.06	.36
(E. Chubocka)	B	.23	1.43	.04	.22
	C	.23	1.62	.08	.24
Humic Eluviated	Aa	.23	0.63	.02	.18
Gleysol	B	.23	1.40	.05	.20
(B. Pearson)	C	.30	1.81	.09	.26
Angus Ridge	Aa	.30	0.85	.04	.24
(A. Wulff)	B	.45	1.44	.05	.36
	C	.30	1.82	.05	.32
Thin Black Solod	Aa	.15	0.75	.01	.13
(T. Sereda)	B	.26	1.17	.02	.16
	C	.41	1.49	.08	.32
Wetaskiwin	Aa	.13	0.60	.02	.12
(F. Bérubé)	B	.30	1.24	.02	.24
	C	.25	1.39	.07	.25
Camrose	Aa	.15	0.83	.03	.14
(A. W. Adam)	B	.26	1.30	.04	.25
	C	.30	1.61	.12	.28
Winterburn	Aa	.60	2.24	.11	.50
(H. Evjen)	B	.36	1.65	.08	.32
Tolmie #1	Aa	.07	0.50	.01	.12
(Vancouver Island)	AB	.08	0.51	.02	.10
	B	.20	1.06	.01	.24
	D	.13	0.76	.01	.16
Tolmie #2	Aa	.05	0.46	.02	.06
(Vancouver Island)	AB	.04	0.63	.02	.04
	B	.15	0.99	.02	.13
	D	.08	0.52	.02	.12
Burford (Ontario)	Aa	.08	0.59	.03	.12
Guelph (Ontario)	Aa	.08	0.72	.05	.12

* A horizon disturbed by cultivation.
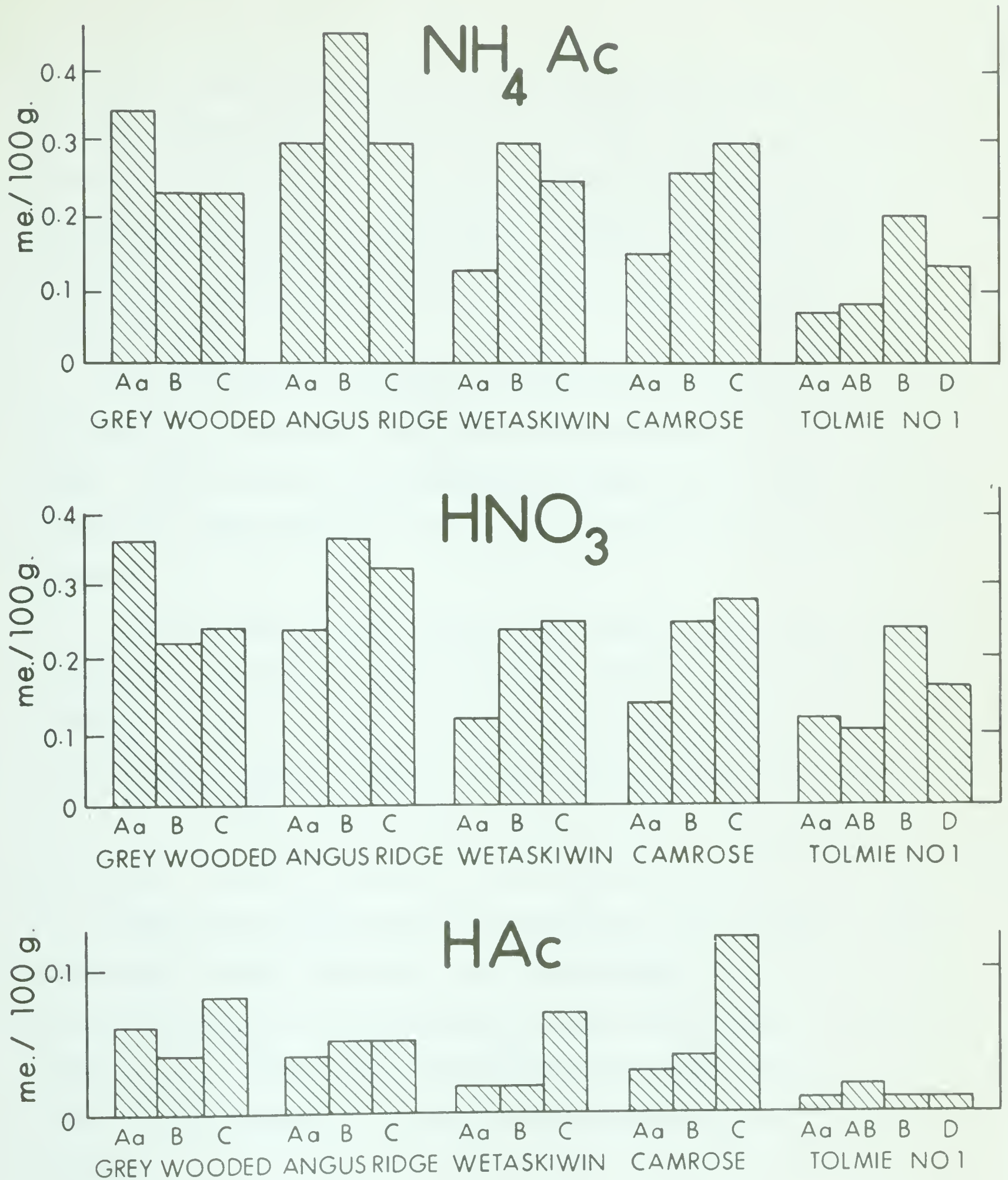
Fig. 2 Potassium extracted with 1N NH₄ Ac, 0.1N HNO₃ and 0.024 N HAc from the Aa, B and C horizons.

Wetaskiwin, Camrose, Tolmie, Burford and Guelph soils of this study.

Only the Winterburn soil has an adequate potassium supply in the surface

horizon and this soil was chosen for comparative purposes because it had

greater than 50 lb. K /ac. by HAc method. The data illustrate the

importance of characterizing the whole profile rather than just the

surface horizon.

The potassium extracted from the Alberta soils with $0.1N$ HNO_3 followed

the same trend as the NH_4Ac extractable with the values being just slightly

lower. Whereas, in the Tolmie, Burford and Guelph soils the HNO_3 extracted

slightly more than the NH_4Ac, but again the same trend was noted for both

methods.

The HAc method extracted less potassium than the NH_4Ac and $0.1N$ HNO_3

although the same general trend is present. The HAc appears to have a dis-

advantage and this is apparent in the Wetakiwin and the Tolmie soils

where the NH_4Ac and HNO_3 methods show differences between the horizons

while the HAc method indicates the potassium to be the same throughout

the profile. By the HAc method the Tolmie, Burford and Guelph soils have

only slightly less potassium than the Alberta soils yet the NH_4Ac and HNO_3

methods show greater differences. The HAc method,due to the small amount

it extracts,appears to be misleading when used in determining the potassium

status of soils, especially for soils with low potassium contents. The

other two methods appear to be superior for determining potassium status

of soils.

(d) Rate of Release.

Potassium released to 5 repeated extractions of boiling N HNO_3 is

considered a good measure of the potassium supplying power of soils, the

results are shown in Table 6 and in Figure 3 for the Wetaskiwin and
Camrose soils. The first extraction removed greater quantities of potassium
than any of the subsequent extractions. In the fourth and fifth extractions
the amount removed, in general was constant and is considered to be an
indication of the soils potassium supplying power (MacLean, 1961).

The surface horizon of the Winterburn soil released more potassium
in the first and subsequent extractions than the surface horizon of the other
soils. The Tolmie, Burford and Guelph soils released lower amounts of
potassium than the other Aa horizons. The surface horizon of the Grey
Wooded soil did not have a greater quantity removed by repeated extractions
than the other horizons even though the NH_4Ac and HNO_3 extractable were
higher in the surface.

In the B horizon more potassium was removed from the Angus Ridge
soil than any other soil which follows the findings by NH_4Ac and HNO_3
methods. As depth in the profile increased the amount of potassium removed
by repeated extractions increased except in the Winterburn soil, where it
decreased.

The total extractable potassium was higher for the Alberta soils than
those from British Columbia or Ontario for comparable horizons. Goettel
(1962) found that generally the amount of potassium decreased with depth
in the profile although some exceptions occurred. The values Goettel found
were all higher than those found in this study.

McEwen and Matthews (1958), MacLean (1961) and Torstensson (1963)
reported that the potassium supplying power and clay content were closely
related. Smith and Matthews (1957) found a correlation between potassium
supplied to successive crops of alfalfa in the greenhouse and the clay
content. The clay fraction released more non-exchangeable potassium to

Table 6

Potassium extracted by repeated extractions with boiling 1N HNO₃

Soil	Horizon	Repeated extractions with 1N HNO₃					Total K extracted	Estimate of more soluble non-exch. K**
		1	2	3	4	5		
Grey Wooded	Aa*	0.56	0.25	0.22	0.18	0.18	1.39	0.49
(E. Chubocka)	B	0.48	0.34	0.26	0.22	0.14	1.44	0.58
	C	0.58	0.37	0.34	0.22	0.14	1.65	0.79
Humic Eluviated	Aa	0.52	0.22	0.14	0.14	0.14	1.16	0.46
Gleysol	B	0.54	0.30	0.18	0.14	0.13	1.29	0.62
(B. Pearson)	C	0.60	0.32	0.20	0.24	0.18	1.54	0.52
Angus Ridge	Aa	0.82	0.34	0.22	0.22	0.20	1.80	0.76
(A. Wulff)	B	1.14	0.40	0.28	0.32	0.24	2.38	1.02
	C	0.84	0.32	0.30	0.30	0.24	2.00	0.68
Thin Black Solod	Aa	0.46	0.18	0.12	0.16	0.16	1.08	0.28
(T. Sereda)	B	0.48	0.25	0.18	0.16	0.13	1.20	0.39
	C	0.78	0.36	0.25	0.16	0.24	1.79	0.75
Wetaskiwin	Aa	0.48	0.22	0.13	0.13	0.16	1.12	0.38
(F. Bérubé)	B	0.62	0.44	0.24	0.26	0.16	1.72	0.72
	C	0.76	0.27	0.23	0.19	0.15	1.60	0.77
Camrose	Aa	0.34	0.14	0.12	0.10	0.10	0.80	0.30
(A. W. Adam)	B	0.74	0.37	0.28	0.16	0.12	1.67	0.99
	C	0.64	0.50	0.32	0.22	0.18	1.86	0.88
Winterburn	Aa	1.00	0.56	0.32	0.36	0.25	2.49	1.02
(H. Evjen)	B	0.64	0.36	0.22	0.22	0.18	1.62	0.64
Tolmie #1	Aa	0.24	0.13	0.12	0.12	0.10	0.71	0.17
(Vancouver Is.)	AB	0.26	0.10	0.08	0.08	0.08	0.60	0.20
	B	0.47	0.16	0.13	0.13	0.13	1.02	0.37
	D	0.46	0.24	0.16	0.12	0.10	1.08	0.54
Tolmie #2	Aa	0.30	0.06	0.04	0.04	0.04	0.48	0.28
(Vancouver Is.)	AB	0.14	0.06	0.06	0.06	0.04	0.36	0.12
	B	0.30	0.06	0.06	0.06	0.06	0.54	0.24
	D	0.34	0.12	0.08	0.06	0.06	0.66	0.36
Burford (Ontario)	Aa	0.32	0.16	0.14	0.12	0.12	0.86	0.26
Guelph (Ontario)	Aa	0.25	0.13	0.12	0.12	0.12	0.74	0.14

* A horizon disturbed by cultivation.

** Calculated by summation of extractions 1, 2, and 3 minus amounts released by extractions 4 and twice 5.

Fig. 3 Potassium extracted by repeated extractions (1,2,3,4,5) with boiling 1N HNO_3

boiling 1N HNO_3 than any of the other soil fractions. Arnold (1962) stated

that potassium release was correlated with the fine clay fraction of the

soil and not the coarse clay fraction. In the present study a relationship

was found between the total potassium removed by repeated extractions and

the clay content. The correlation was 0.594 which although highly

significant by the 't-test' only accounts for 34 per cent of the variation

(R^2 = 0.34). The data show that although the percentage clay generally

decreased in the C horizon the potassium removed by repeated extraction

with boiling HNO_3 generally increases as compared to the B horizon.

The relationship between the various methods for determining soil

potassium values are shown in Table 7. All the correlations are highly

significant, with the relationship between 1N NH_4Ac and 0.1N HNO_3 or 1N NH_4Ac

Table 7. The relationship between various methods
for determining soil potassium

Methods			r-value
1N NH_4Ac	vs.	0.024N HAc	0.849**
0.1N HNO_3	vs.	0.024N HAc	0.810**
0.1N HNO_3	vs.	1N NH_4Ac	0.956**
1N NH_4Ac	vs.	More soluble non-exchangeable	0.833**
1N NH_4Ac	vs.	Boiling HNO_3 (repeated extractions)	0.905**
0.024N HAc	vs.	Boiling HNO_3 (repeated extractions)	0.680**

** Significance at the 0.01 level.

and repeated extractions with boiling HNO_3 being the highest, 0.956 and

0.905 respectively. These methods for determining potassium are all

chemical with the amount removed depending upon the severity of the

treatment. Therefore, one would expect a correlation between methods.

The order of treatments ranked from most drastic to least drastic is repeated extractions with boiling 1N HNO_3, 1N NH_4Ac, 0.1N HNO_3 and 0.024N HAc. Therefore a higher correlation would be expected between boiling 1N HNO_3 and 1N NH_4Ac than between boiling 1N HNO_3 and 0.024N HAc.

Effect of Cropping and Fertilization

Exchangeable potassium and potassium removed by repeated extractions with boiling 1N HNO_3 were determined on the soils from the greenhouse study after the fourth cutting of alfalfa. The 0.1N HNO_3 extraction and the repeated extractions with boiling 1N HNO_3 were performed only on soils from the 20-40-0 and 20-40-60 treatments. Results of the determinations are reported in Table 8.

The 3 barley crops and 4 alfalfa cuts did not reduce the exchangeable potassium, except for the Winterburn soil, as indicated by a comparison before and after cropping (0-0-0 vs 20-40-0). Again, a comparison of these two treatments shows the amounts of potassium extracted from the 20-40-0 treatment by the first extraction with boiling 1N HNO_3 after cropping were similar to those extracted before cropping and fertilization. However, the total amounts removed by 5 extractions were slightly lower after cropping than before. For all soils it can be said that generally the amount extracted for any extraction was less after cropping than before except for the first extraction. Haylock (1956) found the amount removed by the first extraction was less after cropping than before whereas the other extractions remained constant.

The addition of potassium fertilizer to the soils increased the exchangeable potassium with the amount increasing as the additions became larger. Boiling 1N HNO_3 with the first extraction removed more potassium

Table 8

Effect of continuous cropping on exchangeable and non-exchangeable potassium

(me./100 g. air dry soil)

Soil	Treatment	Exchangeable			Repeated extractions in HNO₃						More soluble non-exch. K
		0.024N HAc	1N NH₄Ac	0.1N HNO₃	1	2	3	4	5	Total	
Thin Black Solod (T. Sereda)	0-0-0*	.01	.15	.13	.46	.18	.12	.14	.14	1.08	.28
	20-40-0	.01	.15	.13	.46	.18	.10	.10	.10	.94	.44
	20-40-30	.02	.50	-**	-	-	-	-	-	-	-
	20-40-60	.03	.50	.37	.59	.20	.14	.14	.14	1.21	.51
	20-40-120	.13	1.13	-	-	-	-	-	-	-	-
Camrose (A. W. Adam)	0-0-0*	.03	.15	.14	.34	.14	.12	.10	.10	.80	0.30
	20-40-0	.03	.15	.10	.28	.12	.12	.10	.12	.74	0.18
	20-40-30	.06	.58	-	-	-	-	-	-	-	-
	20-40-60	.15	.73	.50	.40	.13	.10	.10	.10	.83	0.31
	20-40-120	.39	1.30	-	-	-	-	-	-	-	-
Wetaskiwin (F. Bérubé)	0-0-0*	.02	.13	.12	.48	.22	.13	.13	.16	1.12	.38
	20-40-0	.02	.13	.12	.48	.20	.12	.12	.13	1.05	.42
	20-40-30	.04	.59	-	-	-	-	-	-	-	-
	20-40-60	.07	.73	.42	.62	.26	.12	.12	.16	1.28	.56
	20-40-120	.24	1.35	-	-	-	-	-	-	-	-
Winterburn (H. Evjen)	0-0-0*	.11	.60	.50	1.00	.56	.32	.36	.25	2.49	1.02
	20-40-0	.06	.50	.36	1.04	.47	.24	.24	.24	2.23	1.03
	20-40-30	.09	.73	-	-	-	-	-	-	-	-
	20-40-60	.17	.83	.68	1.10	.54	.34	.32	.26	2.32	1.22
	20-40-120	.42	1.40	-	-	-	-	-	-	-	-

* Analysis before fertilization and cropping.

** Analysis not performed.

after cropping from 20-40-60 treatment than from the 0-0-0 and 20-40-0

treatments. In subsequent extractions little or no difference occurred

in the amounts removed, compared to the 0-0-0 treatment. The total

potassium extracted by boiling 1N HNO_3 and the more soluble non-exchange-

able potassium increased for all soils when potassium was added.

Since no reduction in the exchangeable potassium occurred upon

cropping for the 20-40-0 treatment, except in the Winterburn soil,

it appears that the potassium in the soils was at or near the equilibrium

level when cropping began. Similar small reductions in exchangeable

values when soils were near the equilibrium level have been reported by

Reitemeier (1951) and Smith and Matthews (1957). The results also indicate

that in the 20-40-60 treatment part of the added potassium was fixed

by the soil since the total potassium extracted by repeated extraction

with boiling 1N HNO_3 was larger. This fixed potassium was removed by the

first extraction with boiling 1N HNO_3 but not by the .1N HNO_3 pretreatment.

There is disagreement on the problems associated with adding potassium

to the soil. Kresge and Younts (1962), Robinson et al. (1962), Page et al.

(1963) and Torstensson (1963) reported that added potassium is fixed

and made unavailable to plants, thus reducing the effect of the fertilizer

treatment and causing the need for higher rates of application. It was

reported (Wells and Parks, 1961; Robinson et al., 1962; Page et al., 1963)

that added potassium is fixed in the surface few inches of the soil unless

heavy applications are applied. Kresge and Younts (1962) and Robinson et al.

(1962) reported a spring application of potassium was available to only

the first crop of hay as the remainder was fixed and not available to the

second crop. Contrary to this, Richards and McLean (1961) found that soil

with artificially fixed potassium added to untreated soils gave as

good results as untreated soils with KCl added, showing that fixed

potassium was available to the plants. McLean and Simon (1958) and

Richards and McLean (1961) reported that most of the added potassium

fixed by drying was released with boiling N HNO_3 and was largely

recoverable by cropping.

Mineralogical Analyses

The clay fractions contained montmorillonite, illite, kaolinite,

chlorite, and quartz. Illite and kaolinite were present in larger

amounts in the coarse clay fraction than in the fine clay fraction.

Conversely, the fine clay fraction contained more montmorillonite than the

coarse clay fraction. Gravenor and Bayrock (1961), Pawluk (1961) and

Goettel (1962) found similar results and stated that the fine clay

fraction is predominately montmorillonite and the coarse clay fraction

predominately illite.

The main objective of the mineralogical analysis was to compare the

relative amounts of 10-11 $\overset{o}{A}$ minerals between various horizons within

four selected profiles and in a general way to rank these profiles

on the basis of their 10-11 $\overset{o}{A}$ content. The ratio of the height of the

10-11 $\overset{o}{A}$ peak to the height of the peaks of several of the other clay

minerals was calculated for each horizon (Table 9). The 10-11 $\overset{o}{A}$ peak

heights were calculated also (Table 10). The assumption was made that

the clay mineral suite was the same in each horizon and that only the

ratios of the clay minerals varied. Thus film thickness is the only

variable and it should have little effect on the ratios. More analytical

studies would have to be performed in order to get better semi-quantitative

Table 9

Peak height ratio of Illite to Montmorillonite, Kaolinite, Quartz and Chlorite

Soil	Horizon	Montmorillonite 2.0-0.2 microns	Montmorillonite <0.2 microns	Illite 2.0-0.2 microns	Illite <0.2 microns	Kaolinite 2.0-0.2 microns	Kaolinite <0.2 microns	Quartz 2.0-0.2 microns	Quartz <0.2 microns	Chlorite 2.0-0.2 microns	Chlorite <0.2 microns
Humic Eluviated Gleysol (B. Pearson)	A	0.17	0.02	1.0	1.0	0.38	0.38	0.26	0.09	3.50	1.50
	B	0.08	0.03	1.0	1.0	0.45	0.50	0.27	0.13	4.25	
	C	0.08	0.04	1.0	1.0	0.50	0.63	0.38	0.19	2.67	1.67
Thin Black Solod (T. Sereda)	A	0.39	0.03	1.0	1.0	1.00	0.31	0.29	0.10	2.00	
	B	0.05	0.01	1.0	1.0	0.57	0.25	0.20	0.05	1.14	
	C	0.04	0.01	1.0	1.0	0.58	0.50	0.16	0.07	1.40	0.67
Winterburn (H. Evjen)	A	0.34	0.07	1.0	1.0	0.85	1.00	0.48	0.15	3.67	3.00
	B	0.09	0.02	1.0	1.0	0.77	1.33	0.56	0.31	3.33	
Tolmie #1 (Vancouver Is.)	A	0.29	0.25	1.0	1.0	0.36	0.30	0.24	0.27	0.31	0.86
	AB	0.19	0.13	1.0	1.0	0.33	0.25	0.22	0.13	0.38	1.33
	B	0.25	0.03	1.0	1.0	0.43	0.17	0.23	0.05	0.25	0.50
	D	0.12	0.03	1.0	1.0	0.83	0.14	0.22	0.05	0.50	0.67

* Setting 4-1-8.

Table 10

Peak height above background of clay minerals in some soils in this study

Soil	Horizon	Montmorillonite 2.0-0.2 microns	Montmorillonite < 0.2 microns	Illite 2.0-0.2 microns	Illite < 0.2 microns	Kaolinite 2.0-0.2 microns	Kaolinite < 0.2 microns	Quartz 2.0-0.2 microns	Quartz < 0.2 microns	Chlorite 2.0-0.2 microns	Chlorite < 0.2 microns
Humic Eluviated Gleysol (B. Pearson)	A	84*	134*	14*	3*	16*	8*	52*	34*	4*	2*
	B	224	256	17	8	38	16	64	60	4	0
	C	200	244	16	10	32	16	42	52	6	6
Thin Black Solod (T. Sereda)	A	36	172	14	5	14	16	48	50	7	0
	B	156	276	8	2	14	8	40	40	7	0
	C	168	384	7	4	12	8	44	56	5	6
Winterburn (H. Evjen)	A	64	84	22	6	26	6	46	40	6	2
	B	114	252	10	4	13	3	18	13	3	0
Tolmie #1 (Vancouver Is.)	A	17	24	5	6	14	20	21	22	16	7
	AB	32	32	6	4	18	16	27	30	16	3
	B	24	66	6	2	14	12	26	38	24	4
	D	43	72	5	2	6	14	23	40	10	3

* Setting 4-1-8.

estimates of the clay minerals present. The relative amounts of 10-11 $\overset{o}{A}$ peaks as indicated by the ratios were compared to hydrolyzable (boiling N HNO_3) and exchangeable (N NH_4Ac) potassium to find if a relationship occurred.

In the Gleysolic soil there was relatively more illite in the coarse clay fraction of the A horizon than in the same fraction from the B or C horizons. The illite content of the fine clay fraction was small and nearly constant for all horizons.

The Solod soil had little illite present in the B or C horizons compared to the A horizon in both the fine and coarse clay fractions. Broadening of the illite peaks suggested some weathering had occurred.

The A horizon of the Winterburn soil contained relatively more illite in both the fine and coarse clay fractions than the B horizon. The amount of illite in the fine clay fraction was much less than in the coarse clay fraction.

X-ray data indicated that the Tolmie soil is highly weathered because vermiculite, interlayer minerals and chlorite peaks are present. The intensity of the montmorillonite and illite peaks were small (Table 10). The illite peaks were broad indicating weathering had occurred. Amounts of illite in the coarse clay were nearly equal in all horizons while the A horizon had the most illite in the fine clay fraction. The Tolmie soil appears to be more weathered and has less 10-11 $\overset{o}{A}$ minerals than the Alberta soils studied.

Reitemeier (1957) and MacLean and Brydon (1963) stated that pure illite is an effective supplier of potassium. Gardner (1960) reported illite or micaceous material giving a 10 $\overset{o}{A}$ peak as an important source of potassium in some Western Oregon soils, with small quantities of illite

being responsible for the potassium supply. Grissinger and Jeffries
(1957) found release of potassium related to hydrous mica content.

Goettel (1962) stated the Airdrie soil, high in potassium,had
relatively more illite than the other soils tested. The 10 $\overset{o}{A}$ peak
intensities of all the soils Goettel studied were higher than those in this
study except for the Winterburn soil. Hydrolyzable and exchangeable
potassium values reported by Goettel were higher than for these soils,
except for Winterburn, with Airdrie having the highest.

Comparing the relative amounts of illite in the horizons of these
soils to the corresponding exchangeable and hydrolyzable potassium it was
found that no consistent relationship exists except for the Winterburn
soil. In the Gleysolic, Solod and Tolmie soils the exchangeable and
hydrolyzable potassium increased for the lower horizons, while the relative
illite content decreased. Both the illite content and exchangeable and
hydrolyzable potassium decreased in the B horizon of the Winterburn soil.

The work of Arnold (1962) suggests that estimates of 10 $\overset{o}{A}$ peak
intensity can not be used for prediction of potassium releasing power.
MacLean and Brydon (1963) could find no relationship between potassium
release and illite content, and Gardner (1960) found illite in some soils
with low potassium release values. The illite present in the soils Gardner
studied was in degraded form showing that the presence of micaceous
material does not necessarily imply high potassium release values. Rouse
and Bertramson (1949) and Arnold (1962) found potassium release and fine
clay content were highly correlated while illite is predominately in the
coarse clay fraction. Therefore illite content according to this concept

should not be used to predict the potassium releasing power of a soil and the present study seems to support this viewpoint.

The source of potassium could be from minerals other than the 10-11 $\overset{o}{A}$ group existing in the clay and non-clay fractions of the soil. Feldspars, muscovite and biotite (Leaf, 1959; MacLean and Brydon, 1963) are possible sources of potassium. Gardner (1960) found the potassium micas released potassium more readily than the potassium feldspars. This suggests that the mineralogical composition of a soil should be taken into account when determining the potassium potential. Reitemeier et al. (1947) found potassium differences of soils depended on the stage of development or degree of weathering. Soils having large quantities of unweathered primary minerals containing potassium produced extremely high exchangeable and hydrolyzable potassium content. Gardner (1960) also found soils in which little weathering had taken place had unweathered illite and other potassium bearing minerals and gave a high rate of potassium release. Reitemeier et al. (1949) stated that the quantities of potassium removed by crops dictates the length of time soils will be able to supply enough potassium for plant growth. In Alberta plant growth is often limited due to climatic conditions and it is possible that potassium release from the non-exchangeable form is sufficient for growth.

Plant Analyses

(a) Greenhouse.

Plant analyses were performed on the alfalfa from the 20-40-0 and 20-40-120 treatments of the second and third cuttings of the greenhouse experiment (Table 11).

Table 11. Potassium content of alfalfa in greenhouse study
(per cent of oven dry weight, average of 6 replicates)

| Soil | Cutting | Treatment | |
		20-40-0	20-40-120
Thin Black Solod (T. Sereda)	2nd	0.91	2.96
	3rd	0.59	2.75
Camrose (A. W. Adam)	2nd	0.80	2.83
	3rd	0.66	2.67
Wetaskiwin (F. Bérubé)	2nd	0.52	2.75
	3rd	0.38	2.50
Winterburn (H. Evjen)	2nd	1.69	2.72
	3rd	1.75	2.50

The potassium content of plants from the 20-40-0 treatment were
below 1 per cent except for the Winterburn soil. Lawton et al. (1954)
stated that the critical potassium level for alfalfa and clover was 1
per cent on dry weight basis. Chandler et al. (1945) reported that
yield response usually resulted from fertilization when the potassium
content of alfalfa at the early bloom stage was less than 1.25 per cent
and seldom occurred when above this amount. By these standards the
plants from the 20-40-0 treatment were deficient except for the Winter-
burn soil and should have responded to added potassium. Increased alfalfa
yields did result from potassium fertilization except on the Camrose
and Winterburn soils. Potassium content from the 20-40-120 treatment was
2.50 per cent or over. Morrison (1956) stated that average potassium
content of alfalfa hay was 1.97 to 2.14 per cent. Contents greater than
these amounts are due to luxury consumption and indicate that plants are
getting more than sufficient potassium.

(b) Field.

Plant samples were taken from the 0-0-0 treatment of 4 experimental
sites in 1963, and from the 0-0-0 and 0-0-50 treatments in 1964, and

analyzed for potassium. Results are presented in Table 12.

Table 12. Potassium content of legume in field experiments
(per cent oven dry weight, average of 2 replicates)

Soil	Year	Treatment 0-0-0	0-0-50
Angus Ridge (J. Blondheim)	1963	1.08	-*
Angus Ridge (C. Murphy)	1963	1.81	-
Gleysol (B. Pearson)**	1963	1.42	-
	1964	1.44	1.81
Angus Ridge (A. Wulff)	1963	1.24	-
	1964	1.20	1.55

* Analysis not performed.
** Clover.

Only the check was analyzed in 1963 due to lack of rainfall between the time of fertilization and harvest. Goettel (1962) found that added potassium was not utilized by plants the year of application due to lack of rainfall. In 1963 the plants from the 0-0-0 treatment had less than 1.97 to 2.14 per cent average potassium content for alfalfa hay reported by Morrison and discussed earlier. The alfalfa from the Blondheim site was just over the 1 per cent critical level suggesting the soil was deficient in potassium.

In 1964 the potassium content of the samples in the 0-0-0 treatment were again low with the levels the same for the Gleysol and the Angus Ridge soils as the previous year. The addition of 50 lb./ac. of potassium increased the potassium content but they remained below the values sited by Morrison.

SUMMARY AND CONCLUSIONS

By plotting on a map the potassium values of soil samples analyzed in the Soil and Feed Testing Laboratory, areas which had values less than 50 lb./ac. (HAc method) became evident. It was the purpose of this study to characterize some of these soils. Greenhouse, field and laboratory studies were made in order to determine the chemical properties and to find whether crops grown on these soils respond to added potassium. Soils from British Columbia and Ontario which are known to be deficient in potassium were analyzed in the laboratory as a comparison to the Alberta soils.

The greenhouse study showed increased yields occurred on soils with soil test values below 50 lb./ac. of K. However, greenhouse cropping may not give the same results as field cropping since only the surface horizon was used. Furthermore, under field conditions roots of legume crops permeate an unknown volume of surface and subsurface soil, thus the relative importance of surface and subsurface soil as a source of potassium is not known. Furthermore, greenhouse and field climatic conditions differ greatly from each other.

In the field experiments no significant responses to potasssium fertilizer occurred in the two years that tests were carried out. However, moisture conditions were below normal and in most cases growth was below average thereby creating little demand for nutrients.

Potassium extracted from the Aa horizon by 1N NH_4Ac was highest for the Winterburn soil (0.60 me./100 g.) which was chosen for comparative purposes because it had greater than 50 lb./ac. of K   (HAc method). The other Alberta soils with values less than 50 lb./ac. of K (HAc method)

had NH_4Ac values ranging from 0.13 (Wetaskiwin) to 0.34 (Grey Wooded),

while the Burford, Guelph and Tolmie soils ranged from 0.05 to 0.08

me./100 g. The 0.024N HAc extracted 0.11 me./100 g. from the Winterburn,

while the other Alberta soils tested ranged from 0.01 (Thin Black Solod)

to 0.06 (Grey Wooded) and the Burford, Guelph and Tolmie ranged from

0.01 to 0.05 me./100 g. Quantities extracted with 0.1N HNO_3 were 0.50

me./100 g. for the Winterburn, while the other Alberta soils tested

ranged from 0.12 (Wetaskiwin) to 0.36 (Grey Wooded) and the Burford,

Guelph and Tolmie ranged from 0.06 to 0.12 me./100 g.

All three methods were significantly correlated with each other.

However, the 1N HN_4Ac and 0.1N HNO_3 appear to detect differences between

soils with low test values better than the HAc method.

Repeated extraction with boiling 1N HNO_3 gave an estimate of rate of

potassium release. Winterburn released the greatest quantity of potassium

2.49 me./100 g. The other Alberta soils ranged from 0.80 (Camrose) to 1.80

(Angus Ridge), while Burford, Guelph and Tolmie soils ranged from

0.48 to 0.86 me./100 g.

With all 4 methods of extracting potassium it was found that the

amounts of potassium extracted increased with depth in the profile

except for the Winterburn and Grey Wooded soils where the Aa horizon

had the largest amounts extracted.

Continuous cropping in the greenhouse did not reduce the 1N NH_4Ac,

0.024N HAc or 0.1N HNO_3 extractable potassium except for the Winterburn

soil. It did slightly reduce the total potassium extracted by 5 extractions

with boiling 1N HNO_3. The addition of potassium at 60 lb./ac. of K

before each crop increased the potassium extracted by all methods indicating

that more potassium was added than used by the plants. The initial

extraction with boiling 1N HNO_3 extracted more potassium from the

potassium fertilized soils than the unfertilized soils indicating some

of the added potassium was fixed by the soil.

Mineralogical analyses appear to indicate that no correlation

existed between the intensities of 10-11 $\overset{o}{A}$ peaks or the ratio of

10-11 $\overset{o}{A}$ peaks to other clay mineral peaks and the amounts of exchangeable

or hydrolyzable potassium. It is suggested that the extent of weathering

and the presence of other potassium bearing minerals may be responsible

for this poor correlation.

The analysis of plant material from the greenhouse showed that

other than the Winterburn soil the alfalfa from the check plots of the

Thin Black Solod, Camrose, and Wetaskiwin were all below 1 per cent, which

is considered to be a critical level. Legumes from the fertilized and

unfertilized plots in the field trials contained more than the 1 per cent

critical value but less than the average content reported for alfalfa

hay by Morrison.

All the Alberta soils with soil test values less than 50 lb./ac. of

K (0.024 HAc) had higher potassium contents than soils from British

Columbia and Ontario. However, most of them would be placed in the low

class by Oregon standards and in the medium class by Minnesota and

Wisconsin standards indicating potassium applications would be recommended

for cereals and forages under their conditions. Responses obtained in

the greenhouse and the potassium content of plants from the field plots

further support the viewpoint that these soils have low potassium contents.

The lack of response under field conditions emphasizes the need for

further tests to determine whether the soils are low for Alberta conditions

and also to determine the importance of increasing amounts of potassium with increasing depth in the profile. Soil moisture conditions were poor during the two years of testing and growth was less than normal thereby creating a low demand for potassium.

The results of this study indicate that the level of 50 lb./ac. of K (determined by HAc) is a reasonable value for dividing the soils with low potassium content from those with medium potassium content.

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